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An Integrated, Tiered Approach to Monitoring and Management of Dredged Material Disposal Sites in the New England Region

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The DAMOS (Disposal Area Monitoring System) Program has evolved a great deal over the past 15 years in the course of monitoring nine regional and several project-specific disposal sites extending from western Long Island Sound to Maine. During the past four years, scientists at NED and SAIC, along with a Technical Advisory Committee (TAC), have developed a tiered monitoring protocol for the DAMOS Program to provide guidelines and a logical structure for the monitoring program, and to establish a system of decision criteria based on program management objectives.

This tiered monitoring protocol is a major advance from past monitoring programs, because it is based on the testing of null hypotheses. The null hypotheses that serve as a foundation for the DAMOS tiered monitoring protocol help focus the field monitoring program on critical issues for making management decisions. This eliminates the tendency for a "shotgun" approach to monitoring. Each observation is required to answer a question, and each question ultimately leads to a management decision.

The tiered monitoring/management program was designed to address **compliance** with permit regulations, **model verification** to check the validity of predictions and assumptions underlying the tiered sampling design, and identification of long-term **trends** in the environment that might be related to disposal activity. Separate tiered monitoring protocols have been developed for both confined and unconfined dredged material mounds in open-water containment disposal sites.

This is one of the first tiered programs developed for dredged material disposal site monitoring and, as such, it has evolved through a process of periodic public review and has undergone substantial revision. The flow charts presented in this document are not inflexible protocols, but instead provide a framework for NED's overall management and monitoring of the DAMOS disposal sites; their application requires a degree of both common sense and best professional judgement. It is the intention of the DAMOS program to continue to revisit the monitoring and management issues periodically to improve the program further as we gain a better understanding of the environmental responses to dredged material disposal.

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This report is dedicated in memory of
Dr. Willis E. Pequegnat
1914-1994

TABLE OF CONTENTS

Dredging and disposal activities within the jurisdiction of the U.S. Army Corps of Engineers New England Division (NED) have had a high public profile over the past two decades because of potential water-use conflicts in this highly populated region. To address regional concerns as well as federally mandated criteria and guidelines for open-water dredged material disposal, NED initiated the DAMOS (Disposal Area Monitoring System) program in 1977. The DAMOS program has evolved a great deal over the past 15 years in the course of monitoring nine regional and several project-specific disposal sites extending from western Long Island Sound to Maine. During the past four years, scientists at NED and SAIC, along with a Technical Advisory Committee (TAC), have developed a tiered monitoring protocol for the DAMOS program to provide guidelines and a logical structure for the monitoring program, and to establish a system of decision criteria based on program management objectives.

This tiered monitoring protocol is a major advance from past monitoring programs, because it is based on the testing of null hypotheses. A null hypothesis is a statement about the status of a system of interest relative to a control or alternate condition; it is the basis for all statistical testing as well as the underpinning for good experimental design. The term "null" used in this context means that the initial assumption or hypothesis is one of no difference between the status of an "experimental population" (e.g., the density of opportunistic pioneering fauna at a disposal site) versus a "control population" (e.g., the density of opportunistic pioneering fauna on the ambient bottom). The acceptance or rejection of the null (no difference) hypothesis is based on a mathematically derived probability value (chosen beforehand) that sampling or chance alone would explain any difference found between the two populations assuming the null hypothesis is true. The null hypotheses that serve as a foundation for the DAMOS tiered monitoring protocol help focus the field monitoring program on critical issues for making management decisions. This eliminates the tendency for a "shotgun" approach to monitoring. Each observation is required to answer a question, and each question ultimately leads to a management decision.

The success of the DAMOS effort recently has been recognized by the National Academy of Science (National Research Council, 1990). An important attribute of a responsive and evolving program is that it requires periodic scrutiny for technical and managerial improvement. The tiered monitoring protocol presented in the pages to follow is the product of both internal and external technical critique and review.

The questions that helped structure the tiered monitoring protocol are:

- What are the central questions and/or null hypotheses?
- What are the sources of uncertainty in our existing knowledge?
- What are the most efficient data gathering methods to address these

issues, and how can they be structured around clearly-stated null hypotheses to provide unambiguous results?

The tiered monitoring / management program was designed to address **compliance** with permit regulations, **model verification** to check the validity of predictions and assumptions underlying the tiered sampling design, and identification of long-term **trends** in the environment that might be related to disposal activity. This technical review is an attempt to assess the adequacy of the DAMOS program to accomplish these tasks.

Like many other Corps of Engineers' offices, the NED manages both dispersive and containment disposal sites. Only one site in the New England region (Cornfield Shoals in Long Island Sound) is managed as a dispersive site; the other eight are containment sites. This document only addresses a tiered, integrated monitoring/management protocol for open-water dredged material disposal sites located in low-energy, depositional environments (containment sites). Within these sites, disposal mounds may consist of confined aquatic mounds (capped) or unconfined mounds (not capped). Separate tiered monitoring protocols have been developed for both confined and unconfined dredged material mounds in open-water containment disposal sites.

Three tiered protocols are reviewed in this document:

- A management overview structure which starts with a proposed project and, through a structured series of logical decisions, determines if a proposed project is suitable for dredging and disposal. During this procedure, an evaluation is made regarding the extent of chemical and biological testing needed to make decisions about how the project is to be managed (unconfined open-water disposal, capping, upland disposal, no disposal, etc.).

- A three-tiered monitoring plan is presented for an unconfined (i.e. non-capped) open-water dredged material mound. The null hypothesis tested in this plan is based on an expected (model) successional sequence for benthic invertebrate recolonization. Anomalies result in further evaluation of potential physical and chemical disturbances. If toxic responses are suspected, management decisions and remediation actions are proposed.

- The third structured protocol consists of two tiers and is designed for confined aquatic disposal, or capped mounds. The observational program is based on a null hypothesis that capping has isolated sediment contaminants effectively. The monitoring initially considers the efficiency of physical capping and then follows benthic succession within the first tier. If anomalies are observed then both the capped sediments and colonizing organisms are tested for contamination at the next tier. If the tests indicate that contaminants are migrating

through the cap, management actions are proposed.

Given the reality of fiscal constraints on budgets coupled with the number of disposal sites that require monitoring, there was a clear need to streamline the approach to disposal site monitoring that historically had been employed under the DAMOS program. The development of these tiered monitoring protocols is our attempt to fulfill this need. This is one of the first tiered programs developed for dredged material disposal site monitoring and, as such, it has evolved through a process of periodic public review and has undergone substantial revision. The flow charts presented in this document are not inflexible protocols, but instead provide a framework for NED's overall management and monitoring of the DAMOS disposal sites; their application requires a degree of both common sense and best professional judgement. It is the intention of the DAMOS program to continue to revisit the monitoring and management issues periodically to improve the program further as we gain a better understanding of the environmental responses to dredged material disposal.

"We are beset in these days of impact assessments, environmental monitoring and all, with the problem of studying a complex system in some way that will convince us we know what is going on and that we can predict the effect of our actions on this system. Meetings on this subject tend to fragment into lobbyists for the various approaches. The Baconian ideal of compiling all knowledge and consigning it to the computer to tell us what to think about it all is the ultimate extreme on one side, and the notion that one (or perhaps two) numbers from a dying mussel may be all we need is the other extreme of the ancient problem of deducing the state of affairs from diverse concepts based on limited vision or perhaps no vision at all, but a disconnected set of tactile impressions of the elephant. Or, to put it another way, how can we be certain we are not still prisoners in Plato's cave?"

J. W. Hedgpeth (1978)

1.0 INTRODUCTION

The ports and harbors of colonial New England historically were the front doors of coastal settlements. Since the industrial revolution, ports and harbors have become the back doors receiving wastes and effluents from growing metropolitan areas. This legacy has placed a high level of management responsibility on the U.S. Army Corps of Engineers New England Division (NED) in terms of maintaining active harbor channels and berthing sites in areas that in many cases have received a wide range of contaminated sediments over a long period of time. The highly populated coastal region in New England also presents many potential conflicts with the dredging and disposal process. All of these factors require an effective means of managing dredging to avoid conflicts and, at the same time, maintain or improve the quality of New England coastal waterways. In 1977, NED initiated the DAMOS (Disposal Area Monitoring System) program to address the environmental concerns associated with open-water dredged material disposal. Over the past 15 years, the DAMOS program has evolved both in the types of sampling gear used as well as the overall approach or philosophy to disposal site monitoring and management.

During the past three years, scientists from NED, Science Applications International Corporation (SAIC), and from the DAMOS Technical Advisory Committee[1] (TAC) have met periodically to correct some of the shortcomings in the DAMOS program that typically are associated with most monitoring programs (e.g., Boesch, 1984; Green, 1984; Segar and Stamman, 1986; Bernstein and Zalinski, 1986). This group's goal has been to develop an integrated, tiered approach to the DAMOS monitoring program that is focussed on addressing specific program objectives and will provide useful information on which management decisions can be based. The ideal end-product would be (1) an evolving monitoring program with an

1 Members of the DAMOS TAC are Drs. B. Bernstein, H. Bokuniewicz, I. Duedall, R. Engler, and W. Pequegnat

iterative feedback linked to both (2) disposal site management decisions and (3) the initial dredged material permit screening guidelines; each of these three items would change over time in reaction to results, actions or standards from the other two items.

Ever since the National Environmental Policy Act (NEPA) was passed in 1970 which required that an Environmental Impact Statement (EIS) be prepared for all proposed legislation and all major Federal actions that could affect the quality of the human environment, the past two decades have witnessed the rapid proliferation and quiet death of countless consulting companies, monitoring programs, and voluminous reports produced in response to perceived or actual short-term environmental "crises". Unfortunately, there has been a pattern established of poor program design (often the fault of poor legislation; see below) which history has proved is very hard to break. Most monitoring programs (with very few exceptions) have suffered from a lack of focus on clear questions and testable hypotheses, degenerating into a descriptive data collection exercise where exhaustive inventories are produced rather than issue-oriented results (Dayton, 1982; Bernstein and Zalinski, 1986); another specific criticism often cited is a lack of statistical rigor, including poor sampling design and an inability to detect changes (Hurlbert, 1984; Bernstein and Zalinski, 1986; Fredette *et al.*, 1986).

The DAMOS program, being one of the few long-term monitoring programs initiated during the heyday of environmental legislation and persisting to the present, has been no exception to the above oft-cited criticisms. With the advantage of 20-20 hindsight, it is easy to explain why these shortcomings have existed in this monitoring program's structure. The vague guidance for environmental quality or monitoring criteria provided in existing legislation can be cited for contributing to a large degree to the "lack of focus" in this and many other monitoring programs. For example, the references to environmental quality found in the 1977 EPA Ocean Dumping Act regulations are typical of the general language found in most legislation; disposal "will not unreasonably degrade or endanger human health, welfare, or amenities, or the marine environment, ecological systems, or economic potentialities", or present "no unacceptable adverse effect on the marine ecosystem". As Fredette *et al.* (1986) have pointed out, these are noble concepts, but they are not quantifiable in any precise manner. Also, the purpose, monitoring tasks, and objectives of the DAMOS program have evolved and changed quite a bit since 1977, when the program was first initiated. While one can argue justifiably that this constantly changing nature of the program was responsible to a great extent for the present appearance of what appears to be largely a massive inventory of data, one cannot ignore earlier recommendations made by both the 1979 Scientific Advisory Board formed for the monitoring program design of the original Stamford-New Haven capping project (SAIC, unpub.) and the general public

resulting from the 1985 DAMOS Public Symposium (SAIC, 1986) that the DAMOS program suffered from a lack of clearly-defined, testable hypotheses.

Despite the amount of effort spent by the Corps studying the environmental effects of dredging (e.g., Engler *et al.*, 1990) and the past 13 years of data gathered under the DAMOS program, there is still a need for monitoring the environmental effects of open-water dredged material disposal to better understand and quantify ecosystem response to the disposal activity. If accurate and reliable predictions about the environmental effects of dredged material disposal could be made, there would be no need for the DAMOS program or monitoring of any sort. However, instead of continuing the "retrospective" monitoring (*sensu* Hartung, 1984) which has been done in the past, the intent of this document is to outline a tiered monitoring/management structure which is "prospective" in nature. While retrospective monitoring programs do not determine the magnitude and type of impacts until after data are collected and interpreted, a prospective monitoring program is designed to test site conditions against a previously stated outcome or standards (Moriarty, 1983). However, as will be brought out in the sections to follow, because of the limitations of our knowledge of ecosystem function and the unexpected results which can occur from the interaction of human activities with natural ecological processes, the predicted "outcomes" are often times a best guess. If one defines an experiment as "an action whose outcome we cannot predict precisely or specify beforehand" (i.e., the disposal of dredged material in the natural system), then an alternative frame of reference is to view monitoring as a feedback mechanism providing data about the outcome of experiments (Bernstein and Zalinski, 1986). This admission of fallibility does not detract from the underlying structure or basic value of the monitoring program; it merely requires letting go of the illusion of certainty (Holling, 1978).

This document is the first organized attempt by the program to depart from the cyclical repetition of past mistakes. The remainder of this document will present the three hierarchical management and monitoring strategies developed during the past TAC sessions and provide an explanation for the background and rationale of each element in these plans. The current regulations regarding ocean disposal of dredged material, due to their vague language, provide a wide latitude to each individual Corps district to interpret what exactly are "unreasonable degradation" or "unacceptable adverse effects". However, it is precisely this lack of clear definition in the regulations that have caused most dredged material monitoring programs to appear in hindsight as a haphazard collection of data inventories with no clear purpose in mind; as Green (1979) stated so eloquently in his landmark textbook, "Your results will be as coherent and as comprehensible as your initial conception of the problem." Because

there is a lack of clear guidance or establishment of standards in the regulations, it was necessary to go "one step beyond" the regulations and define standards or acceptable levels of impact against which field results could be tested.

The decision as to an impact being acceptable or unacceptable ultimately depends on "best professional judgement". Best professional judgement is defined here as the summation of all evaluation processes that apply to a project or protocol including public review, EPA and USACOE evaluation of test data, monitoring requirements, outside technical committees, and consultants. In addition to the scientific, technical, and operational evaluations, this judgement also has a social, political, and economic dimension. Ideally, best professional judgements change over time as they benefit from cumulative experience and new information. The development of the monitoring plan presented in this document has benefitted from over 15 years of NED experience with several public and technical program reviews. The knowledge base and "evolution" of this judgement ultimately is determined by managers responsible for dredging and disposal regulation. If the review process is ignored or bypassed, the best professional judgement process obviously is violated. By necessity, these tiered monitoring plans are developmental and subject to review, criticism, and undoubtedly substantial revision in the future.

Following the recommendations of Bernstein and Zalinski (1986), this document will attempt to organize the discussion of each of these tiered monitoring frameworks around the following principles:

- A focus on central questions and/or testable null hypotheses;
- The recognition and identification of sources of uncertainty;
- Data gathering activities structured around statistical models that incorporate null hypotheses and assumptions about uncertainty and variability; and,
- The evaluation of data in terms of their ability to address central questions and/or hypotheses.

Associated with this plan are still a great many details to be clarified and underlying assumptions which may be faulty; these will be identified whenever possible. The important point to bear in mind is that this is a working document that will change along with the focus of the DAMOS program as our base of knowledge increases; it is our responsibility to admit and address honestly our knowledge or technical limitations to insure that our future judgment is not clouded by the illusion of scientific "certainty" or rigor where it really does not exist.

2.0 MANAGEMENT OVERVIEW

All open-water dredged material disposal is subject to the regulatory jurisdiction of NED as defined under Section 103 of the Marine Protection, Research and Sanctuaries Act (MPRSA) and Section 404 of the Clean Water Act (CWA). In order for private applicants or federal maintenance projects to be considered as candidates for open-water disposal, they must first demonstrate the need for open-water disposal and that all practicable alternatives to ocean disposal (Section 103) or estuarine/riverine disposal (Section 404) have been explored and found unavailable or not feasible according to the guidelines. Once these criteria are met, the dredged material must be evaluated for potential environmental impacts in order to determine its suitability for open-water disposal. The logic and structure for this evaluation process has been summarized in the form of a flow chart (Figure 1); each box has been numbered for cross-referencing purposes with the text which follows. Rectangular boxes are known as process boxes and describe actions which take place; diamond-shaped boxes are decision points where questions are posed with a "yes" or "no" outcome. Each of the outcomes from a decision box will lead to another action or decision box. Elongated boxes at the end of a pathway with rounded corners which do not lead to another action or decision box are terminal boxes. **It is important to note that the numbering scheme in this and the remaining flow charts do not imply a rigid rank order or infer a linear protocol which must be followed; it is merely for easy reference with the explanatory text.**

Box 1.1: ***"Project Proposed"***

As outlined in the previous paragraph, the action which triggers this entire open-water disposal evaluation process is an application for a dredging permit at NED. After the evaluation process is completed at NED, all permits are subject to review and comment by federal agencies such as EPA Region I, the National Marine Fisheries Service, and the U.S. Fish and Wildlife Service. In addition, the project is reviewed to see if it conforms to state standards of water quality (401 Certification) and is consistent with the Coastal Zone Management Act (CZM Consistency). With the complete absence of regional near-shore dredged material containment facilities and a paucity of coastal real estate available for nearshore or upland disposal sites in the region, open-water disposal typically is the most feasible option available in New England.

In accordance with the procedures in the 1977 EPA Ocean Dumping Regulations and Criteria (Federal Register, 1977)) applicants are "given guidance" regarding criteria by the joint EPA/COE 1991 Testing Manual "Evaluation of Dredged Material Proposed for Ocean Disposal" (the "Green Book") which defines procedures to evaluate the potential environmental impacts associated with ocean disposal of dredged material. Even though some national guidance is provided in the Green Book, it is

broad and generic, reflecting our general knowledge about processes and impacts. The Green Book guidance is not intended to predict site-specific effects on a national scale; it requires "additional guidance ... necessary to adapt the procedures to Regional situations" (EPA/NED, 1989). The national policy is to provide broadly defined and generic guidance to local EPA and COE districts for regulating disposal within their own regions. This allows each region to review the general guidance in terms of the local environmental settings, dredging needs, disposal options, and economic implications. This document is an attempt to be more specific about the predicted impacts for dredged material disposal in New England waters based on the experience gained over the last 15 years of monitoring under the DAMOS program. It is a matter of time until other EPA/COE regional offices develop similar protocols.

Material to be dredged in New England typically falls into one of three classes:

- Clean, sand-sized sediment containing negligible concentrations of organic or inorganic contaminants;

- Fine sands, silts and clays with varying concentrations of contaminants, some of which exceed State or Federal guidelines; or,

- Fine-grained, generally organic-rich sediments containing some variety of toxic contaminants in concentrations that clearly exceed guidelines and pose potential environmental hazard.

Handling procedures associated with the first and third categories are straightforward. Clean sands can be dredged and disposed at open-water sites or utilized for land-based beneficial uses (e.g., beach nourishment). Removal of contaminated fine-grained material may require special dredging procedures to minimize resuspension, and disposal is carefully engineered and managed. It is the second category of sediments that are more difficult to evaluate; in New England, these constitute the major fraction of material to be dredged.

The first decision point for an applicant is to see if the material proposed falls into the first category; according to the federal criteria (Sec. 227.13(b) in the original 1977 law (Federal Register, 1977), Sec. 225.6 in the 1988 draft revision), material may be excluded from further testing if the dredging site is far removed from known existing and historical sources of pollution (to provide reasonable assurance that the material is not contaminated) <u>and</u> one or more of the three following conditions exist:

- The material is composed predominantly of sand, gravel, or rock (anything larger than silt) and is from areas of high currents or wave energy such as streams with large bed loads or coastal areas with shifting bars or channels;

- The material would be suitable for

beach nourishment or restoration with particle sizes compatible with the material on the receiving beaches;

- The material is comparable in texture and composition to the ambient substratum at the disposal site.

Any applicant who wants to qualify for the above exclusion criteria must present grain size data along with pertinent historical or site-specific information documenting the distance from known sources of pollution.

Box 1.2: "Satisfy Exclusion Criteria?"

The physical testing required by NED for evaluating dredged material for ocean disposal is limited to grain size, total organic carbon analysis, and water content determination (EPA/NED, 1989). The null hypothesis that would be tested in this particular action box is:

H_0: Material at the dredging site has a major modal grain size greater than or equal to fine sand.

Rejection of the null hypothesis would place you in box 1.3; acceptance of the null hypothesis would lead to box 1.9 and allow unconfined open-water disposal.

Underlying Assumptions: The basic assumption is that sand and larger sized particles are chemically inert, relatively free from contaminants, and pose no environmental impact from a chemical or biological standpoint (the only biological impact would be perhaps a change in the type of community that develops on a substratum of a particular grain size).

Sources of Uncertainty: There is a certain amount of subjective judgment involved in the determination of what is "far removed" from historical sources of pollution (i.e., how far is far?). It appears foolish at this point to state arbitrarily a minimum absolute distance to quantify "far" (i.e., "anything greater than ½ mile"), because distance is not necessarily synonymous with chemical isolation, depending on the transport routes available in a particular area. The determination of what is "far" enough will have to be left to one's best professional judgment; if there is any question, it is best to err on the conservative side and proceed to the next level of testing (Box 1.3). Chances are if an area truly is "far removed" from historical sources of pollution, it will be obvious at a first glance (just as Supreme Court Justice Potter Stewart memorably defined pornography by saying, "I can't define it precisely, but I know it when I see it").

Box 1.3 "Bulk Chemical Analyses"

The majority of material dredged in New England does not qualify for the exclusion criteria stated above and the next level of chemical testing is required. The current guidance (EPA/NED, 1989) requires bulk sediment analyses alone for 8 metals (As, Cd, Cr, Cu, Pb, Ni, Hg, Zn), total PCB's, pesticides, and PAH's according to EPA protocols (EPA, 1986). The analytical results are compared with sediment classification guidelines

established by the New England River Basins Commission (NERBC, 1980).

Box 1.4 "Clearly Contaminated?"

Required detection limits for these bulk sediment chemical analyses are given in the guidance document (Table I.A., EPA/NED, 1989). The unstated null hypothesis that would be tested in this particular action box under the current guidelines is:

H_0: Bulk sediment contaminant levels are not significantly higher than those contamination levels classified as "low" in the 1980 NERBC guidelines.

Rejection of the null hypothesis would place you in box 1.5; acceptance would lead to box 1.9 and unconfined open-water disposal.

Underlying Assumptions: The underlying assumption, regardless of which guidelines are being followed, is that the dredging site has been sampled sufficiently to characterize the variability of contaminant levels at the site.

Sources of Uncertainty: There are several very important sources of uncertainty associated with this decision point:

a) As mentioned above, the potential variability in the contaminant level at a dredging site is great, based on the patchiness of sediment types and pollution history of an area. The EPA/NED guidance document is not specific concerning objective standards that determine exactly how many samples need to be taken. A sampling plan is worked out jointly between the NED and the applicant or technical consultants. The NED reviews each plan "for adequacy" based on past knowledge of sampling in the area and information about past spills and point sources of contamination. Even with such a review, contaminants can be distributed patchily within harbors, and it is possible that an approved sampling plan can miss these "hotspots".

b) A total of 8 metals and 3 classes of organics are usually tested, although, where needed, analytes are chosen from a more extensive list. There is no clear guidance regarding what objective standard(s) can be used to classify a sediment as contaminated when there are varying levels in each of these 11 components. For example, it may happen that one or more of the metals from a permit sample may be in the "highly contaminated" class according to the NERBC classification scheme, while the remaining contaminants fall in the "low" or "moderate" NERBC range. These high, low, and moderate designations are based on practical experience and historical information with sediment concentrations in New England ports and harbors. The decision to go to the next action box (and require bioassay testing) is based on best professional judgement. This decision is somewhat subjective, because there is a lack of

documented association of individual chemical concentrations and subsequent biological effect.

c) Even if any particular contaminant levels are high, it has been demonstrated in a number of studies that sediment concentration alone does not reflect bioavailability (e.g., Carpenter and Hugget, 1984). This is why bulk chemistry results alone do not disqualify material for open-water disposal.

The presence of so many uncertainties is why this action box is used merely as a screening level for bioassay/bioaccumulation studies (Box 1.5).

Box 1.5 ***"Bioassay Needed for Further Evaluation?"***

If the levels from the bulk chemical analyses are sufficiently high to cause concern during the review at NED, bioassay/bioaccumulation studies may be needed to determine whether or not capping shall be imposed as a permit restriction, assuming efficient capping is deemed feasible. At this point, permittees can opt just to elect capping (Box 1.8) as opposed to taking the chance on paying for an expensive testing procedure (Box 1.6; cost of approximately $50,000 at the time of this writing) and winding up having to cap their project anyway.

Sources of Uncertainty: There is no null hypothesis being tested at this point. It is really up to the reviewer to decide if:

a) bulk contaminant levels are so high that they exceed legally defined hazardous levels (e.g., CERCLA or Superfund) such that open-water disposal is an unlikely option (Box 1.8); or,

b) there is "reason to believe" or questionable doubt that the material may have an adverse biological impact (again, an undefined concept in the regulations) that will be confirmed by subjecting the material to a bioassay and bioaccumulation laboratory test (Box 1.6). The "reason to believe" may be based on past knowledge of sediment quality in a harbor, the appearance (e.g., an oily sheen) and smell of recovered samples, or field evidence that few (or no) organisms are recovered with the sediment.

A strong recommendation is to explore the possibility of formally defining criteria based on the historical data available for determining when biological testing is required to remove some of the subjectivity from this decision box. For example, some objective criteria are available based on the NERBC (1980) classification scheme for sediment quality in New England and the EPA/COE (1991) Green Book guidance on the Theoretical Bioaccumulation Potential (TBP) for nonpolar organic compounds.

Box 1.6 ***"Bioassay/Bioaccumulation"***

Requirements for biological testing of the material are outlined in the EPA/NED (1989) guidance document,

based on the 1978 EPA/USACOE Green Book. The recent publication of the revised Green Book (EPA/USACOE, 1991) will require that these earlier protocols be revisited and updated at the NED. Whole sediment bioassays are heavily relied upon, while suspended particulate and elutriate testing "may be required under certain circumstances" (page 15, EPA/NED, 1989). As before, these "circumstances" are undefined and left up to the Corps' "best professional judgment"; the general tendency is to err on the conservative side as a safety measure. The organisms acceptable as biological testing species are listed in the EPA/NED (1989) guidance document (Appendix A). Whole sediment bioassays must include 3 species from 3 different phyla: a crustacean, a polychaete, and a bivalve, and bioaccumulation testing must use the survivors of the bioassay test.

Box 1.7 "Toxicity or Significant Accumulation?"

Results from the laboratory bioassay and bioaccumulation tests are compared with results from animals in control sediments (natural sediment free of contaminants to confirm the biological acceptability of the test conditions and the health of the organisms during the test) and reference sediments (sediments from the disposal site reference station that have a similar grain size to the dredged material to reflect conditions that would exist in the vicinity of the disposal site had no disposal taken place). The bioassay tests are for acute response (over 10 and 28 days depending on species), not chronic measures. The unstated null hypotheses in this box are:

$H_0 1$: Mortalities of organisms in sediment from the dredging site are not significantly different from those in reference sediment.

$H_0 2$: Tissue contaminant levels in organisms in sediment from the dredging site are not significantly different from those in reference sediment.

Rejection of either null hypothesis would place you in Box 1.8; acceptance of both will lead to Box 1.9 and acceptability of unconfined open-water disposal.

Underlying Assumptions: These tests are based on the assumption that chronic impacts are either negligible or impossible to assess given the present technological limitations, and that any acute effects detected are due to the contaminant levels and not other experimental variables. The COE and EPA also recognize that there are more potential contaminants present than could ever be tested; there are at least 63,000 organics in common use from a tally over a decade ago (Maugh, 1978), and all chemicals in sediment, biota, or water cannot even be identified or quantified as yet (Malins *et al.*, 1984). There are only a few hundred standards for identifying positively the thousands of compounds now detectable in GC profiles. Even if the technology was present to identify every possible chemical, the cost would be prohibitive, and there would still be no

way of predicting synergistic effects. An underlying assumption is that acute bioassays using "sensitive" organisms (e.g., amphipods) will serve as the marine equivalent of a canary in a mine and detect these unanalyzed "deleterious" unknown chemicals or synergistic effects.

Sources of Uncertainty: Not surprisingly, there are several sources for potential errors:

a) Chronic effects by known, measured contaminants, unanalyzed contaminants, or synergistic combinations are not being assessed. Unfortunately, this determination is beyond the current state of our technology. However, research is currently underway to develop chronic testing and evaluation methods to fulfill the need for such a determination.

b) Bioaccumulation results are acquired only for those compounds/elements specified by NED "in cooperation with other Federal resource agencies" out of the list provided in Table III of the EPA/NED (1989) guidance document (Appendix B); there is a possibility that contaminants either not on the list or selected (i.e, the unknown contaminants) are present in the organism.

c) There is no way to equate statistically significant bioaccumulation (levels in test organisms compared with references) with real biological harm; we do not know what the "normal" range of elements or compounds tested are in natural organisms, and levels can change within the species with ontogeny (lipid content, reproductive state, etc). Unfortunately, there is no way of judging the acceptability of any baseline levels at this point (Peddicord, 1984).

d) Both bioassay and bioaccumulation tests deal with a few selected organisms under controlled conditions; how these findings relate to biological responses under field conditions is not clearly known. These test results are not to be used to address unequivocally any in situ effects, but rather to answer the question of whether or not the contaminants are bioavailable.

e) There is a potential for bioassay results to have confounding variables unrelated to contaminant concentration affecting the final results (e.g., different grain size or organic carbon content between dredging site and reference sediment).

f) Other than limited guidance in the Green Book, there is no clear, written information available for interpreting bioassay or bioaccumulation results. Because there are replicate tests for at least three species, it is quite likely as in the bulk chemistry evaluations to get "hits" in some categories and not in others. It is once again up to the best professional judgment of the individual reviewers whether they want to allow unconfined,

open-water disposal (Box 1.9) or re-evaluate the permit for special management decisions (Box 1.8). Even though one can argue that best professional judgment is still a subjective interpretation, it is important to keep in mind that it would not be the subjective interpretation of one person operating in a vacuum; a reviewer would be operating within a framework of experience within their agency as well as having access to the historical data gathered by the DAMOS program.

Given our present state of knowledge, it is unlikely that many of the issues identified above will be resolved in the short term. Because of the many sources of uncertainty, the general tendency is once again to "err on the conservative side"; the tendency in the past has been to proceed to the options in Box 1.8 if either of the null hypotheses are rejected.

Box 1.8 "Special Management"

One arrives at this box either by having contaminated sediment (as determined by bulk sediment analyses) and electing not to incur the expense of a bioassay (via Box 1.5), or by doing a bioassay/bioaccumulation and showing either significant mortality or significant bioaccumulation (via Box 1.7). At this point, options for disposal include either confined aquatic disposal (i.e., capping) or upland disposal if it is determined that the material is unsuitable for marine environment (i.e., that it will have "an unacceptable adverse effect on the marine ecosystem").

Box 1.9 "Unconfined Open-water Disposal"

One arrives at this box via one of 3 possible pathways:

a) Clean sand or coarser material is being disposed which satisfies the exclusion criteria (via Box 1.2);

b) The material shows no elevated levels of contaminants as a result of the bulk chemical analyses (via Box 1.4);

c) The material did show elevated contaminant levels but no adverse biological impacts as measured by the bioassay/bioaccumulation tests (via Box 1.7).

A permit will be issued with a specified period of validity for disposal at one of the NED's nine disposal sites (project-specific sites are also approved in some cases).

Box 1.10 "Disposal Allowed?"

At this point, the evaluator at NED has material that is slightly or very contaminated that shows evidence of biological impacts. The regulations specifically prohibit materials with PCB's greater than 50 parts per million, radioactive wastes, or inert synthetic or natural materials which may float. Also materials containing any of the following in other than trace contaminants shall not be approved (ODA §227.3(c), 7/29/88:6A revised draft): organohalogen compounds, mercury and mercury compounds, cadmium and cadmium compounds; crude oil and its wastes,

refined petroleum products, and petroleum distillate residues.

Even if none of the prohibited compounds are present, once again there is no clear guidance for what the cut-off point is between capping, upland disposal, and no action. On what basis does one determine that material is too contaminated to cap but not too contaminated for upland disposal, or that material is too contaminated to disturb in any fashion and be left as is (e.g., the "no action" alternative)? Once again, this is relegated to "best professional judgment". It would behoove us to define clear guidelines in the near future if possible, otherwise we are guilty of being just as "vague" as the federal regulations.

If disposal is chosen as the outcome, the unstated null hypothesis is the ultimate environmental question and the reason EPA regulations have been issued over the past two decades:

H_0: Disposal will not degrade the environment unreasonably or endanger human health or welfare.

Unfortunately, this is precisely the sort of loosely-stated null hypothesis which has been criticized by others as being untestable (Green, 1979, 1984; Fredette *et al.*, 1986; Bernstein and Zalinski, 1986) and cannot be answered by any of the previous tests done up to this point. The regulator once again has to exercise his/her "best professional judgment" to determine if they feel the null hypothesis would be rejected (leading to Box 1.11 and no action) or accepted (leading to disposal and the resulting monitoring in Box 1.12). The monitoring programs presented in the sections to follow are attempts to address this vague null hypothesis; as mentioned earlier, if we could predict the outcome of impacts at this point with any certainty, there would be no need to monitor at all.

Box 1.11 "No Action Alternative"

This box is self-explanatory. If it is felt that contaminant levels are too high and disturbance of any sort or any type of disposal would degrade the environment unreasonably, then the only remaining action is not to dredge and leave the material as is or to consider *in situ* capping. In the absence of remediation, the "no action alternative" itself results in negative environmental impacts to water quality through sediment resuspension and continued direct impacts to the organisms inhabiting the location.

As heightened public awareness, the restrictions on ocean dumping, and the need for dredging the heavily-contaminated inner reaches of large harbors in industrialized urban centers in the northeast (e.g., New York Harbor, Boston Harbor, Providence Harbor, New Haven Harbor, etc.) continue to increase in the future, more and more permit evaluations will wind up in either Box 1.8 (Special Management) or Box 1.11 (No Action). If this becomes too critical a problem in the future such that there are severe economic impacts to urban port operations, it will lead most likely to the development of *in situ* remediation techniques.

Box 1.12 "Monitoring"

For marine unconfined or confined open-water disposal, the activities within this particular action box are defined in the next two flow charts. There are two possible routes to arrive at this box. If monitoring is needed as a result of unconfined open-water disposal (via Box 1.9), then the flow chart presented in Figure 2 and explained in Section 4.0 will be followed; if one arrived via Box 1.10, then the flow chart presented in Figure 3 and explained in Section 5.0 will be followed.

The important issue to bear in mind is that the results obtained from activities in the next two flow charts have a feedback function and impact in the overall dredged material management and permit evaluation procedure.

Box 1.13 "Acceptable Impacts?"

It is a given that open-water dredged material disposal will cause near-field impacts and possibly could cause far-field impacts (physical, chemical, and biological), just as storms, river flow, or land run-off can cause both localized and system-wide impacts. What constitutes an acceptable or unacceptable impact and the inherent assumptions leading up to that conclusion is explained in the sections to follow. Detection of unacceptable impacts will lead to Box 1.15, while detection of acceptable impacts will lead to Box 1.14.

Box 1.14 "Status Quo...."

If no impacts are detected, one can conclude that either one is measuring the wrong parameters (i.e., one of the previously mentioned sources of uncertainty is causing an undetected bias in the results), the measurement is not sensitive enough to detect adverse impacts, or that one is disposing of dredged material in an environmentally safe and prudent manner. Continuous detection of no impacts under the proposed tiered monitoring schemes also would indicate that reduced monitoring might be warranted. The question of how long repetitive monitoring should be continued will be discussed in the respective sections on unconfined (uncapped) and confined (capped) aquatic disposal below.

Box 1.15 "Revise the Evaluation and Management Process"

Detection of impacts would lead one to conclude that one or more of the physical/chemical factors has affected the outcome. One very real danger is because of the number of multiple uncertainty factors at several of the above decision points, it is unlikely that a detection of impacts would point clearly to which assumption is false or which source of uncertainty is an important one. If revision of the current evaluation process is required, it would entail restructuring the evaluation criteria down to a finer level of detail to determine exactly where the problem lies by the time-honored technique of inductive inference (Platt, 1964). The sources of uncertainty outlined above potentially could be eliminated by being approached in the following

manner (assuming we are not operating at the limits of current technology and need to make measurements which physically cannot be done): After defining an initial hypothesis to clarify either a particular unknown or source of uncertainty, it would be necessary to devise alternative hypotheses. The next step would entail devising a crucial experiment with alternative possible outcomes, each of which will exclude one or more of the hypotheses. This is the basic idea behind the tiered monitoring flow charts presented below; an ideal evaluation scheme would be a logical tree or framework with branching points like a conditional computer program, where the next move depends on the result of the last calculation. By carrying out each individual experiment and recycling the procedure, making sequential hypotheses to refine the possibilities that remain, one can diagnose accurately where the "weak link" in the initial logic structure really exists.

3.0 APPROACH TO A TIERED MONITORING SCHEME FOR AQUATIC DISPOSAL

Monitoring can be defined in many ways and has had many historical uses, usually with an emphasis on repeated time-series measurements; depending on the needs of a particular situation, monitoring can include conceptual and numerical modeling, laboratory and field research, preliminary or scoping studies, time series measurements, data analysis, synthesis, interpretation, etc. Even though monitoring can be conducted for a variety of purposes, there are three broad categories of problems to which it is applied as a solution (National Research Council, 1990):

- Compliance, to ensure that activities are carried out in accordance with permit requirements or regulations;
- Model verification, to check the validity of assumptions or predictions generated for sampling design, permitting, or evaluation of management alternatives such as when to cap, etc.;
- Trend monitoring, to identify and quantify longer-term environmental changes hypothesized or anticipated as a possible consequence of human activity. A well designed trend monitoring program should be able to identify natural as well as anthropogenic effects.

Aspects of the proposed DAMOS tiered monitoring program address all three categories; fortunately, there are a host of excellent works that provide advice on the design and implementation of environmental monitoring (e.g., Holling, 1978, Green, 1979, 1984; Beanlands and Duinker, 1983; Rosenberg *et al.*, 1981; Bernstein and Zalinski,1986;Fredette *et al.*, 1986). However, before launching into an explanation of the first tiered monitoring flowchart (Figure 2), it would be worthwhile to review the background of thought instrumental in structuring this particular monitoring plan specifically designed to address the regional concerns and environmental impacts of dredged material disposal in New England.

3.1 Objectives

Monitoring of dredged material disposal sites has four primary objectives: (1) assuring that disposal operations (both federal and permit) are completed as directed (compliance monitoring); (2) verifying that disposed sediment and the interaction of the benthic community behave as expected during and following disposal (model verification); (3) providing information that will allow optimum utilization of the disposal sites (trend monitoring); and, (4) assuring that disposal activities are in compliance with environmental laws and regulations (compliance and trend monitoring).

The second and third objectives may have different approaches depending upon whether the site being managed is a dispersive or non-dispersive site. There is only one dispersive site, Cornfield Shoals,

among the nine DAMOS sites; the tiered monitoring schemes presented in the sections to follow apply only to non-dispersive sites. At non-dispersive (containment) sites, disposed sediment accumulates on the bottom and eventually will reach a depth at which either the deposit is subjected to erosive forces, depths become a hazard to navigation, or the volume of sediment disposed at the site reaches the physical limits of the site's capacity. At dispersive sites, the objective is to dispose of sediment with the intention that it will be transported away from the site without long-term accumulation and without adverse environmental impacts. Tiered monitoring schemes for dispersive sites (i.e., model verification) have not been developed as of this writing.

Managing the physical aspects of dredged material disposal in order to optimize site use (including conduct of capping operations where appropriate and selection of the precise disposal point(s) within the site) requires that monitoring be conducted to determine the lateral distribution and elevations of disposed sediment mounds, to confirm that capping operations conform to project specifications, and to allow detection of deviations from expected disposed sediment behavior (including stability of capped mounds). Information from monitoring then can be used to modify disposal operations as conditions warrant. This may include modifying disposal techniques, relocation of the disposal point within the site boundaries, creation of "bowls" to provide areas for accepting and capping contaminated material, or addressing a need to repair portions of eroded caps.

The fourth objective is the key issue with which we are dealing in this document. As mentioned previously, open-water disposal is regulated under Section 404 of the Clean Water Act and Section 103 of the Marine Protection, Research, and Sanctuaries Act. The language of these laws regarding marine environmental impacts is very general and in essence states that disposal must not cause unreasonable adverse impacts. Compliance with environmental laws and regulations relating to the disposal of dredged sediment requires that disposal activities, including the actual presence of dredged sediment in the region, do not result in adverse effects on marine fisheries and other valuable marine resources. How we get from these generally stated but critically important laws and regulations to the specifications for a well-designed regional monitoring program is the challenge that faced the DAMOS TAC.

3.2 Background Assumptions

At the initial TAC meetings, a philosophy for ecological monitoring was constructed by listing assumptions on which this general philosophy was based. These assumptions also provided a basis for determining if specific proposals for monitoring in the project area would be considered seriously as elements of the final Ecological Monitoring Plan (EMP). The assumptions were as follows:

(a) Ecological processes are studied most effectively by recognizing the

range of potential cause-effect relationships that may exist between project activities and physical-chemical environmental alterations as well as probable biological responses to those alterations.

(b) Relationships among physical, chemical and biological elements are naturally complex and vary in the degree to which they are understood. Uncertainty and complexity are increased by apparent conflicts between agencies and institutions which are politically as well as technically motivated. We attempted to achieve an objective and scientific approach as the common ground for discussions about the monitoring program.

(c) Direct short-term physical-chemical and biological impacts affected by dredging and disposal are not the principal concerns of the monitoring program, because scientific experience can argue effectively that these impacts are either not a cause for concern, or they are manageable. An example of the former is the direct effects of dredging and disposal-induced suspended sediment concentrations on estuarine fishes; an example of the latter is the concentration of suspended sediments in the effluent from a dredged material containment facility. The principal concerns of the monitoring program are: (1) indirect physical-chemical environmental alterations, i.e., habitat alterations that may be influenced by dredged material disposal operations and (2) the probable biological responses to these alterations.

(d) Not all elements identified as candidates for incorporation into the monitoring program were selected. The selection process considered the following factors for including or excluding a potential monitoring element:

(i) <u>The strength of the relationship between a candidate element and a project-induced environmental alteration</u>. Studies recommending the monitoring of non-specific indicators of environmental stress would produce information that would be very difficult to interpret unless techniques existed that could be used to separate project-induced stresses from other causes of biological stress acting on the project area. Responses that would be related uniquely to the disposal activity were preferred.

(ii) <u>A relationship between information produced by a monitoring element and criteria that would be defined and used to determine the significance of an observed change</u>. All monitoring elements can produce data, and a subset of elements will produce data that can be used to document the occurrence of a "change". The question is,

how much of a change is ecologically unacceptable? Any change, if it is to be defended as a real change, must be statistically significant, but statistical significance does not necessarily equate with probable ecological significance (Peddicord, 1984; National Research Council, 1986).

(iii) <u>A relationship to possible management or remediative action</u>. This means simply, if an ecologically unacceptable adverse impact is documented by the monitoring program, can the impact be managed and thereby reduced in the future, or remediated? If not, there may not be a defensible reason to undertake monitoring that particular element.

(iv) <u>The ability to generate interpretable quantitative data</u>. For example, quantitative data from observations of plankton and nekton communities may be collected, but they are much more difficult and costly to obtain than quantitative vegetation or benthic invertebrate community data. However, it is paramount to keep in mind at all times that having quantifiable raw data may not address the public concerns directly or the specific needs of the decision makers. Data are merely individual facts, whereas information is data that have been organized, synthesized, and processed for a particular purpose (National Research Council, 1990). As Drucker (1988) expressed so aptly, "Information is data endowed with relevance and purpose. Converting data into information thus requires knowledge."

(e) Results of an EMP could be (and were during the WLIS trial in the Second District Federal Court) drawn into litigation. Methods used for all elements of a monitoring program should maintain reasonable scientific standards for precision and accuracy. Formats for information output must emphasize visual clarity and graphic impact. This means the monitoring program should not encourage the development of final products composed of unsynthesized tabulated data, species lists, or conclusions based on derived ecological indices, all of which may be subjects of questionable interpretation, endless scientific argument, or speculation.

(f) In order for the field monitoring results to be used realistically to affect management action, the EMP <u>must</u> rely primarily on sampling techniques with rapid data return. For example, the final EMP should <u>not</u> include elements with sample and data analyses requiring more than six months (or some other prescribed and reasonable time period, albeit arbitrary to a degree) following each set of field

observations. In other words, it should be possible to describe system conditions that are no more than a few days to two months old.

(g) An EMP must be adaptive. Elements should be deleted if additional work on these elements seems unlikely to produce additional valuable information. Other elements may be added if an effective argument can be made for the addition. Funds always will be limiting, therefore the addition of new elements most likely will be contingent upon the deletion of others.

3.3 Building A Logical Structure

The next step entailed the construction of a framework or structure for identifying, examining, and displaying probable relationships. Without a structure, one could respond to endless claims about project impacts without a logical and graphical basis for considering the reasonableness of those claims. Three basic questions were asked initially:

(a) What specific activities (dredging techniques, disposal operational control, etc.) are associated with dredged material management operations within the DAMOS Program?

(b) What physical and chemical environmental alterations are associated with those activities?

(c) What biological responses are associated with those physical or chemical environmental alterations?

Information about project activities (such as dredging techniques, volumes, etc.) is usually "given". Primary environmental alterations and direct biological impacts resulting from dredging and dredged material disposal operations can be described adequately from previous research and dredging operations experience. Secondary environmental alterations, particularly longer-term changes affected by the altered disposal site conditions, are not known quantitatively and cannot be predicted accurately without considerable effort.

The concerns about impacts of dredged material disposal operations on the ecological resources of the project area were approached by devising a plan for linking secondary environmental alterations to probable changes in the structure and function of biological constituents. The three TAC meetings were directed to define which relationships ultimately would structure the monitoring plan. Initial efforts were focussed at identifying specific information resources and needs; these included physical processes, ecological structure and function, and the hypothesized physical-chemical-biological linkages which existed.

The physical processes identified were the behaviors of new dredged material during its descent to the bottom and following its deposition on the bottom. Decisions about non-physical elements proposed for incorporation into the EMP would be facilitated by the existing

management/monitoring structure, because the same individuals would be involved in designing and performing both the physical monitoring effort and the EMP. For ecological structure and function, it was agreed that considerable data and other information exist which describe the environment. These data were identified to exist for all DAMOS sites given the 10-year history of the monitoring program; there was still a need for considerable review to determine their relevance and, where appropriate, information needs to be extracted and synthesized (e.g., the white papers identified and written during the past two years on contaminant sediment flux, capping effectiveness, fisheries resources, and the capping monograph).

The focus of the most intense discussions revolved around describing the physical-chemical-biological linkage(s). If monitoring is approached as an experiment as suggested earlier, several advantages almost inevitably follow. First, a carefully designed monitoring system is likely to be established which is capable of gathering the data necessary to test the predictions contained in the initial assessment. Second, the study's boundaries also will be established, with efforts directed to the places where effects are most likely to occur. Determining study boundaries in space and time also would help to identify all interest groups and political jurisdictions likely to be affected by the project. It also was recognized that if those groups are involved in the planning from the beginning, costly legal battles and delays potentially can be avoided.

3.4 Development of DAMOS Tiered Monitoring Strategies

Of the nine regional disposal sites in New England, eight are considered to be containment sites; of these, the three in Long Island Sound (Western Long Island Sound, Central Long Island Sound, and New London Disposal sites) are in relatively shallow water (less than 40 meters) and closed for 4 months out of the year (June through September) due to seasonal restrictions on dredging. While the other four sites in deeper water receive dredged material on a year-round basis (Cape Arundel, Portland, Rockland, and Massachusetts Bay Disposal sites), the three Long Island Sound sites offer a unique opportunity for monitoring biological impact and the process of ecosystem recovery because of the temporary hiatus in disposal each year and the management practice of building multiple, discrete mounds within each site. At each of these three sites, mounds are built as a result of sequential disposal operations over the course of one disposal season (e.g., the FVP study in Central Long Island Sound) or over a few seasons due to routine permit and maintenance dredging (the disposal point is moved after the mound apex is between 3-4 meters above ambient depth). While near-field, short-term impacts are studied easily at any of the DAMOS disposal sites, this management practice at the three shallow sites in Long Island Sound also allows monitoring of long-term impacts in the absence of continuous disturbance.

Routine physical monitoring (repetitive precision bathymetric and REMOTS® surveys to map the physical shape, areal extent, and long-term stability of the disposal mounds) occurs at all the active disposal sites on an annual basis. These activities serve as both compliance monitoring (e.g., to verify all material is within the designated site boundaries and adequate operational control of disposal has been achieved by dredging contractors) and model verification (e.g., mound height, areal extent and long-term stability are as predicted by Corps of Engineers' numerical models). It was the trend monitoring addressing the short and long-term biological resource impacts that was the main focus of the TAC's activities.

The primary vectors for adverse impacts to organisms at dredged material disposal sites are physical and chemical alterations to the native sediments or the water column. Both of these vectors can be of concern when dredged sediment is involved, because the grain size of the sediment may represent either a very different bottom type than that of the region around the disposal site, or the sediment may contain contaminants that are either acutely or chronically toxic or can be biologically accumulated and transferred within the food web. In these instances, the management objectives are to contain sediments and isolate any associated contaminants within the disposal site so that they are not available to biological organisms in quantities sufficient to cause adverse effects.

The biological impact component of most monitoring programs often has provided very little information that could be applied directly to the formulation of disposal management decisions. This is not necessarily because the monitoring programs did not or could not detect changes in the environment, but because it was unclear whether detected changes indicated adverse conditions or not. As emphasized earlier, monitoring programs also have failed in many other ways, including lack of clear objectives, inadequate sampling designs, etc. Our objective was to overcome these common inadequacies and address the disposal-related environmental (biological) impacts through a tiered monitoring approach. The steps necessary to achieve this end were: (1) identifying the resources to be protected (being as specific as possible); (2) predicting the processes, specific magnitudes, and areal extent of change that would be necessary to bring about an impact; (3) incorporating monitoring tools with a rapid data return so that field results could be used to make management decisions; and (4) recognizing there are limited resources and a need to develop the most parsimonious monitoring plan.

It was recognized early on that developing specific categories of what were or were not adverse effects would be a difficult and probably impossible task. This was because of the infinite combinations of situations that could be envisioned, and because of the diversity of scientific opinions that subjectively would judge each condition. Certainly it would be

possible to describe scenarios on either end of the spectrum (infinitesimally small changes or large scale annihilation) upon which a majority of resource managers could reach consensus whether or not they would be considered adverse; however, it would be the vast middle ground that would lead to heated and unresolvable debate.

Nonetheless, given our knowledge of the constituents of dredged material, its physical and chemical behavior, and known responses of biological communities to disturbance factors, it was possible to outline (with a reasonable degree of certainty) the steps that would need to occur before an event of sufficient magnitude to be considered adverse would occur. Therefore, even if we have not defined the precise line at which a non-adverse condition becomes an adverse condition, the inherent assumption was that we could monitor for changes in the necessary precursors that eventually would lead to an adverse impact. An essential element of this approach was to monitor within a reasonably scaled domain in which we realistically could expect to detect change based on the magnitude of anthropogenic activity.

Each tier of the monitoring plan was structured to be focused on detecting change relative to a specific, conservative, early warning threshold. Typically, lower tiers focussed on processes that need to first occur in order for the undesired biological impact to occur, while the highest tiers focussed on changes in the resource itself. The intent for this tiered strategy was to prevent adverse impacts from occurring, because early warnings of the potential for such an occurrence would be provided rather than the traditional approach of merely searching for the endpoint of impact.

It is important to note that an early warning threshold is not intended to represent a point for panic but instead an indication that there is <u>potential</u> for increased risk, because the system did not behave as predicted. This also serves as an indication that the model on which the prediction was based is faulty in some way and therefore needs to be re-evaluated. In the meantime, disposal activities can be modified (if necessary) before the situation progresses further and while investigations are completed at the next tier of monitoring. Conclusions reached at this higher monitoring tier could eventually permit a return to the lower tier or result in a long term change in monitoring and/or site management approach.

The specific threshold developed for a tier may be somewhat arbitrary by nature (both in magnitude and areal extent), especially if there is little scientific evidence around which to build the tier. This is not inherently faulty, because the primary objective of the threshold is to provide a conservative decision point around which a manageable (i.e., well-defined study domain) and interpretable monitoring plan can be structured. <u>This point can not be overly stressed</u>, for without an established (perhaps even arbitrary) benchmark <u>against</u> which to measure change and <u>at</u> which

re-evaluation is appropriate, interpretation of environmental monitoring results will continue to be an exercise in futility and of little use to the resource manager.

At the majority of the DAMOS disposal sites in New England, there are no notably unique commercial or socially-important living resource concentrations other than some common demersal fish and lobster populations. These populations of motile organisms will demonstrate some temporary, near-field perturbation during actual dredged material disposal operations. Most disposal mounds become subsequent enhanced sites of secondary benthic production following the initial disturbance and actually serve to concentrate lobster and demersal fish populations. However, even if this enhanced secondary benthic production did not occur, the area of sea floor affected by disposal mounds is so minuscule on a regional basis that it would be impossible to measure any detectable effect on these living resources at the population level.

The continuous, background physical monitoring that occurs almost every year during the DAMOS program addresses concerns about off-site net transport of sediments. Identification of offsite transport would violate the initial assumption that these locations are containment sites and require the development of tiered strategies to address potential impacts upon fishery or socially important (i.e., whale-watching industry) resources through either smothering (e.g., oysters), toxic effects, or indirect impacts on a forage resource. The committee did not devote time to this issue, because the one premise about which everyone felt confident from more than 10 years of DAMOS monitoring was that the disposal mounds at the eight containment sites are stable, and erosion is not occurring to any measurable degree. A principal concern being addressed in the two tiered plans for open-water (i.e., non-capped) and capped disposal mounds presented below is the potential for transport of sediment-associated contaminants from the mound to the food web, where it ultimately could affect humans through seafood consumption. Another concern addressed by these plans is that disposal activities not have adverse ecological consequences such as decreasing productivity of resource species.

4.0 TIERED MONITORING SCHEME FOR UNCONFINED AQUATIC DISPOSAL

4.1 Background

Unconfined aquatic disposal in New England takes place in most cases on low kinetic energy, silt-clay bottom types in water depths of 20 to 90 meters within a few kilometers of shore. Biological resources of concern tend to be demersal fish and crustaceans (such as lobsters), because they provide a direct link via the food chain to human health. The direct effect of disposal on these commercial resources is difficult to evaluate for two primary reasons:

- These secondary consumers are mobile (many are migratory); and,
- They have relatively long life spans.

This means their physiological condition is a function of the quality of habitats that they have lived in throughout their life history. For this reason, if such species are sampled from a disposal site, it is not possible to attribute their specific condition to disposal activities or disposal materials with any degree or certainty. This is the same reason why disposal site monitoring does not include phytoplankton, zooplankton, or nekton as sentinel monitoring species.

Demersal nekton species are also difficult to sample quantitatively on disposal sites because of the relatively small area of the bottom that may be occupied by disposed material. If sampled, it is not possible to determine how long a sampled specimen has been in residence on the disposal mound. This makes it impossible to evaluate exposure history.

Finally, the direct effects of disposal activities on the behavior and long-term physiological responses of demersal fish and crabs or lobsters are poorly known. We have no indices or coefficients (e.g. acute toxicity or tests for sublethal effects) that allow one to quantify direct exposure effects on demersal predators. Because of all of the above shortcomings, the effect of disposal on commercial species is best inferred from the effects of disposal on their food (prey) resources.

4.1.1 Underlying Assumptions

Because of the difficulties with measuring the direct effects of disposal on benthic predators, a surrogate "effects" parameter is required. This surrogate parameter is the food sources of demersal fish and crustaceans: sedentary or relatively immobile benthic invertebrates that colonize dredged materials. These species usually are abundant on disposal sites; individuals spend all of their benthic life cycle on disposal mounds and are intimately associated with both the sediment solids and pore waters through burrowing, feeding, and respiratory activities. These prey species are the best time-integrator of habitat quality and site conditions. Because the prey may be consumed by demersal fish and crustaceans, the underlying

assumption is that if the rate of secondary production of prey species on the disposal mound is equal to or greater than the ambient bottom, the foraging value of the bottom will not have been compromised by disposal.

Secondary productivity of prey species is used here to mean the change in benthic biomass per unit time following cessation of disposal. A corollary to this definition is that if these benthic invertebrates are eaten by demersal species, the prey are replenished rapidly by recruitment.

Quantification of secondary benthic production is a very time-consuming and costly task involving time-series sampling of the bottom for determination of the dry weight and shell-free biomass (and/or caloric content) of colonizing species. Because of the need for rapid data turnaround at reasonable cost, the DAMOS TAC adopted a surrogate measure of secondary production involving the enumeration of colonizing polychaetes (Stage I sere) from REMOTS® images and relating these abundances to known turnover rates of these species (McCall, 1977 and Rhoads, McCall, and Yingst, 1978). This task is made relatively easy because only a few species participate in early succession.

Earlier research studies in Long Island Sound by McCall (1977) and Rhoads *et al.* (1978) showed that rates of secondary benthic production (gm/m^2/day) on areas of "disturbed" seafloor was 2 to 6 times greater than on the ambient bottom. Further, most of this enhanced production is related to the massive sets of larvae of spionid, capitellid, or oweniid polychaetes that initially colonize disturbed habitats (Stage I seres). The basic assumption is that the productivity of the bottom can be deduced or inferred from the standing stock densities of pioneering polychaetes. The densities of these polychaetes can be estimated from REMOTS® images by counting the number of tubes projecting above the sediment surface (number per linear centimeter across the 15 cm width of the optical window). This number squared and expressed as number of tubes per cm^2 can be used as the unit of comparison for making estimates of secondary production in space and time. It is assumed that all or most of the tubes contain living polychaetes and that these polychaetes provide a major potential fraction of the food for foraging fish and crustaceans. This assumption also is based on observations from laboratory microcosm experiments (Germano, 1983) that abandoned tubes disintegrate rapidly. However, if the status of the tubes is questionable, some limited grab sampling can be done to resolve this question.

In addition to the phenomenon of larval recruitment, the variables including the physical properties of disposed sediment, sedimentary processes, and the chemistry of disposed materials which also can affect rates of colonization and secondary production must be included as "feedback" factors in the monitoring of disposal site biological impacts. The assumption here is that the rate of recruitment of the bottom (and hence rate of succession) is limited by physical and chemical

properties of sediments.

To summarize the hierarchy of surrogate measures that provide the foundation for this particular tiered plan:

- Enumeration of polychaete tubes at the sediment-water interface

→ is a surrogate measure for:

- Densities of opportunistic colonizing polychaetes

→ which is a surrogate measure for:

- The rate of benthic secondary production of prey species

→ which is a surrogate measure for:

- Life history impacts and population densities of commercially important demersal fishery species

→ which is a surrogate measure for:

- An early warning signal that impacts of disposal may affect human health.

It also should be noted that the proposed monitoring protocol (Figure 2), while structured to recognize the potential toxic effects of sediment on colonizers through reduced recruitment densities, does not address questions of bioaccumulation. The contaminant load of the tissues of colonizers potentially may be transferred to higher trophic levels. This is recognized as an important shortcoming of the monitoring protocol but, at this time, no Standard Operating Procedure (SOP) exists for analyzing and evaluating contaminant concentrations in pioneering species. The reason for this is that pioneering polychaetes (e.g. spionids) have a very small dry weight/individual. Bioaccumulation studies require between ca. 2-4 grams dry weight of tissue for analysis. The NED presently is developing a field method for efficiently concentrating sufficient biomass for this purpose, but the technique has not yet been field tested. In the past, a surrogate equilibrium species (Nephtys incisa) has been used to check tissue contaminant levels on a sporadic basis; up to this point, invertebrate field bioaccumulation studies have not been applied routinely to disposal site management. If it can be determined that Stage I field bioaccumulation studies are a technically feasible option, then this particular monitoring technique may be worked into the tiered plan to address this specific concern.

4.1.2 Sources of Uncertainty

One could look at the hierarchy of surrogate measures above and conclude that the foundation upon which this tiered plan is structured is

tenuous given the long list of surrogate measures. However, one must be realistic about both expectations for monitoring programs and practical aspects of sampling and data return rates. Also, this plan was developed to provide the DAMOS managers at NED with early warning measures for potential problems with existing management or monitoring practices. It is foolhardy to think that all sources of uncertainty can be eliminated from a monitoring program. The best approach is to admit its existence and recognize that it must be dealt with (Bernstein and Zalinski, 1986). Some sources have even gone so far as to argue that identifying the sources and consequences of uncertainty are more important than making predictions of impacts (National Research Council, 1986).

The sources of uncertainty inherent in the overall structure of the tiered plan are related to the actual utilization of the enhanced secondary benthic production by demersal fish and crustaceans. This only becomes an important issue if bioaccumulation by opportunistic benthic species really is occurring.

Another source of uncertainty is related to what specific prey species are participating in early succession (Stage I seres). It usually is not possible to make taxonomic identifications from REMOTS® photographs. The DAMOS program is rather singular among current dredged material disposal monitoring programs by the infrequent use of traditional benthic sampling in the routine monitoring protocol. Early in the DAMOS program numerous traditional benthic samples were taken. Comparison of these results with REMOTS® images showed that the images could be used to identify the successional status of the bottom accurately. Because the REMOTS® information is very cost effective and provides rapid data return, sediment-profile imaging has been the preferred protocol. If detailed taxonomic data are not needed to address a specific null hypothesis, there is no reason to spend the considerable time or expense to collect that information. If "ground-truth" benthic samples are needed at any point to address a specific management issue or null hypothesis, they can be obtained to provide taxonomic identifications, population density measures, or biomass estimates.

The uncertainty of relating tube counts in REMOTS® photographs to living polychaete counts also can be resolved by "ground-truth" sampling. However, our experience has shown that the tubes of pioneering polychaetes rapidly decompose and disintegrate following death of a worm. Foraging predators also will ingest the tube as well as the worm, so the standing stock of tubes closely reflects the standing stock of polychaetes. We note however, that we have observed dense aggregations of empty tubes of Stage II seres (e.g., <u>Ampelisca abdita</u>) in REMOTS® photographs, apparently related to local bottom water hypoxia. This condition is easily recognized from the condition of the tubes. In the absence of dissolved oxygen near the boundary layer, the amphipods leave the bottom

and emigrate or die, and the tubes become darkened by sedimentary sulfides. Bacterial degradation of the tubes results in tube fragmentation. Although the tubes remain identifiable, it is clear from their condition that such populations have experienced local extinction. This is an example of being able to recognize retrograde succession (decreased secondary production) from a death assemblage.

There also may be statistical uncertainty about the representativeness of samples. REMOTS® surveys need to be designed to account for both small and large-scale spatial variability. Because field sampling is efficient and analysis costs are a fraction of those associated with traditional benthic sampling, both instantaneous replicates (to characterize within-station variability) and multiple stations along transects across disposal mounds (to determine gradients and characterize large-scale variability) are taken. It is important that a sufficient number of stations be spread-out over the entire surface of a disposal mound and not limited just to the mound apex. The top of a disposal mound may experience scour, resulting in an accumulation of coarse shell and sediment. This scour surface is not typical of the overall disposal mound, so it is important that the REMOTS® sampling locations be selected to account for this patchiness in sediment textures.

4.2 A Three-Tiered Monitoring Protocol for Unconfined Disposal Mounds

As stated in the section above, the focus of the monitoring effort is to determine the effect of disposal on the secondary benthic production. The overall null hypothesis being tested is:

H_0: On an unconfined disposal mound, dredged material disposal will result in benthic population density (a surrogate for production) greater than the ambient condition.

The objective of this hypothesis is to verify that the disposed sediments are not having toxic effects as predicted during the initial sediment evaluation (permitting) process.

A three-level tiered monitoring protocol was designed (Figure 2). The first tier relates biological responses to disposal on a population and successional level. These processes are measured against a reference condition on the ambient bottom. The second tier involves the potential for sediment physical factors (mass properties, scour, deposition) to affect colonization. The third tier is focused on the potential for sediment chemistry to affect colonization rates and population density.

4.2.1 Tier One: Biological Processes and Related Management Decisions

Box 2.1 ***"Assess Stage I Population Density....."***

Most dredging and disposal at the three Long Island Sound DAMOS disposal sites takes place in the winter and early spring months to avoid apparent conflict with reproduction

and recruitment of shellfish beds located in harbors near navigation channels. Dredging operations are terminated in the late spring, during the period of intensive recruitment. Experience has shown that disposal mounds are well-populated by pioneering polychaetes within 1-2 weeks following cessation of disposal operations. Because it is unrealistic to assume that monitoring cruises always can be scheduled contractually to occur immediately after disposal stops, a 4 to 12 week period was chosen to allow sufficient time to schedule field operations while still insuring that any enhanced recruitment phase can be detected.

Box 2.2 "Is Stage I Population Density Greater Than Reference?"

Because newly constructed disposal mounds represent competition-free space and the sediment usually is organically enriched over the ambient bottom, disposal mounds experience a dense, generally uniform recruitment of pioneering polychaetes over the entire surface. The only noted exception to this general "rule of thumb" is the mound apex, which may experience localized scour and erosion (see boxes 2.5 - 2.6 with accompanying discussion). The unstated null hypothesis being tested is:

H_0: The population density of opportunistic polychaetes on the disposal mound as detected in REMOTS® photographs is not significantly less than that on the ambient seafloor outside the disposal site boundaries.

If no further disposal takes place, the population of pioneering polychaetes may converge with the ambient bottom after a period of two years or more. Therefore this hypothesis states a prediction that is valid for only active disposal sites.

The high rate of colonization is documented from REMOTS® images by counting the number of tubes per linear centimeter along the sediment-water interface. These densities are compared with mean densities from appropriate reference stations located outside the designated boundaries of the disposal site. At present, three reference stations are sampled at each site. The selection of "appropriate" reference stations will include the following factors:

1. More than one reference location outside the disposal site is needed to characterize the ambient bottom adequately (Hurlbert, 1984).

2. The reference stations should have had the same community structure as the (pre)disposal mound area (determined by a baseline survey).

3. The reference stations should have a similar sediment type as the (pre)disposal mound location. The reference station should show no physical or chemical evidence of historical disposal.

4. The reference stations and disposal mound should be located within comparable water depths and as near to one another as possible without subjecting the reference stations to the possibility of

contamination by disposal operations or post-disposal transport. This can be done by locating the reference station at a position that is offset from the major downstream transport direction(s) of the disposal site.

The question arises what is considered a significantly lower population density on the disposal mound which would trigger monitoring efforts to be initiated in the next lower tier (Box 2.5 in Tier 2)? No absolute density can be cited as a yardstick until historical REMOTS® photographs from immediate post-disposal surveys are examined with this objective in mind. One must also take into account natural year-to-year variability in recruitment of different pioneering species. The important measure is a test of significance between the population mean for the disposal mound compared with the reference stations. Selection of the level of significance to reject the null hypothesis will be a judgement on the part of the resource manager. It is not necessary to set high levels of significance for this test. It may be sufficient for management purposes to detect that the disposal site has mean population densities that are 2 times lower at the disposal mound at 80% of the station replicates than on the ambient seafloor before rejecting the null hypothesis and proceeding to Box 2.5. These kinds of judgements about decision thresholds initially must be based on historical data and be revised over time as information is accumulated about the year-to-year variability in this measure.

Box 2.3 "Expected Response, No Immediate Action Required..."

If population densities of pioneering polychaetes are equal to or higher on the new disposal mound than the ambient seafloor within 4 - 12 weeks after disposal has ceased, this is the predicted response of normal recovery following a disturbance; there is no need for additional testing or monitoring at this point.

The frequency of periodic monitoring will depend on the political or ecological sensitivity of the disposal site or operation. If high-resolution monitoring is required, the first year's monitoring may involve an additional late summer and/or late fall surveys. Otherwise, repeated surveys on an annual basis are all that is required to monitor the normal development of subsequent successional stages.

Underlying Assumptions: The population and successional response is used as an indicator that colonization is not being inhibited by physical or chemical factors specific to the disposal mound. However, this does not mean that bioaccumulation is not taking place. As stated in Section 4.1, methods for analyzing tissue contaminant levels in pioneering polychaetes do not exist at this time. Once these are developed, it would be possible to insert another level of assurance to check the initial evaluation protocol by analyzing tissue contaminant levels in pioneering polychaetes. This would verify that there is no danger of biomagnification as a result of disposal activities. Until

these analytical techniques are developed, however, we are resigned at this point to having only an acute mortality response of Stage I species as a trigger to indicate our evaluation protocols are faulty.

Sources of Uncertainty: Even though colonization is proceeding normally, bioaccumulation still could be occurring and never be detected. However, if one has any level of confidence in the initial permit evaluation process, the possibility of this occurrence would be low enough to eliminate this possibility as a real concern.

Box 2.4 "Stage 2 or 3 Community Develop After N+1 Years?"

In the second year of monitoring, under normal rates of successional change, one expects the progressive addition of Stage II and III taxa. This commonly is accompanied by the presence of less dense populations of Stage I sere species in subsequent years. This assumes that all disposal has stopped and the successional process is uninterrupted by further disposal or other sources of disturbance (e.g., bottom scour by a hurricane). If the disposal mound is disturbed, the successional status of the mound may revert to a Stage I sere and would trigger an evaluation of causality in tiers 2 or 3.

Stage II seres (tubicolous amphipods) can occur as early as the end of year one (3-6 months after disposal operations have ceased). Because the mound apex is usually sandier than the rest of the mound, tubicolous amphipods may be aggregated on the mound apex or distributed in patches over other parts of the deposit. The presence, timing, and persistence of Stage II seres is less predictable, and they may or may not be an important faunal element in subsequent years.

Stage III assemblages also may populate a disposal mound in the first year as part of a secondary succession (the process of reestablishment of conditions similar to the original community after a temporary disturbance). Stage III species are capable of immediately colonizing the thin flanks of a disposal mound as adults by burrowing upward through the thin disposal overburden. The appearance of species on parts of the mound that are much thicker than 20-30 cm requires larval recruitment or recruitment of free swimming polychaete epitokes (modes of initiating primary succession). Deposit-feeding taxa recruiting in this way usually appear on disposal mounds in the second to third years (assuming no further disposal or major physical disturbance takes place to retrograde the succession). The unstated null hypothesis being tested is:

H_0: Stage 2 or 3 assemblages (deposit-feeding taxa) are present on the disposal mound one year from cessation of disposal operations.

Once again, data are collected with REMOTS® technology; acceptance of the null hypothesis would lead back to Box 2.3 and provide verification that

the evaluation of the sediments during the permitting process was correct. Rejection of the null hypothesis would lead to the next level (Box 2.5 in Tier 2).

The frequency of successional monitoring can be decreased to once per year or less in the n+1 and following years. A late summer to autumn survey is adequate to map the distribution of well established adult populations. Deposit-feeding taxa are recognized from REMOTS® images by the presence of feeding voids at depth in the sediment. Once these taxa are recruited in the spring, it takes the whole summer for them to grow and move into the deeper sediment layers. Well-developed feeding voids are produced during the summer and fall when water temperatures are high and benthic metabolic rates are correspondingly high. By mapping these seres in the later summer or autumn, one is more likely to characterize successional stages accurately than if surveys were conducted in the winter or early spring when benthic organisms are relatively inactive.

Once a disposal mound converges with the ambient seafloor (reference stations) in terms of the frequency of encountered equilibrium successional stages, monitoring may be reduced to once-every-other year or be tied to specific pre-conditions such as reactivation of an area for disposal or passage of a major storm. The frequency of long-term monitoring of disposal mounds that continue to yield expected responses (i.e. monitoring results go no further than Tier 1) is a management decision based on the sensitivity of the site to fishing interests, vulnerability of the site to storm surges, or the occurrence of regional hypoxia.

4.2.2 Tier Two: Physical Effects and Related Management Decisions

Box 2.5 "Evaluate Physical Effects"

Tier 2 variables are addressed only if anomalous colonization rates are observed in the Tier 1 monitoring ("no" outputs from Boxes 2.2 or 2.4, Figure 2). If anomalous rates of colonization are documented in Tier 1, we attribute this to physical or chemical properties of the deposited dredged material.

Box 2.6 "Has Change in Physical Attributes of Mound Occurred?"

If one arrives at this box via Box 2.2, initial recruitment patterns would be anomalous if the sediment grain-size of the initial dredged material deposit (e.g., a high sand component) is different than the ambient bottom (e.g., a primarily silt-clay bottom). If one arrives via Box 2.4, the physical effects that are known to affect the normal (i.e., expected) patterns and rates of colonization adversely are sediment erosion and scour. This process commonly is associated with the apex of disposal mounds; it is quite possible for the tidal stream to diverge and increase in velocity (and turbulence) as it passes over the mound. Surface sediment scour results in a loss of fines, and a coarse residue of shell and sand may armor the surface. The initial period of scour

will remove any larval set, so the mound apex is usually slower to recruit than the rest of the deposit. Secondly, the armored surface will be faunally distinct from the rest of the deposit because of the coarse grain size. Attached epifauna (e.g., hydroids) and other sedentary or attached organisms may form a distinct species assemblage that is different from the rest of the disposal mound and the reference stations. The unstated null hypothesis being tested is:

H_0: The sediment grain-size major mode on the disposal mound is not different from the ambient seafloor.

Sediment grain-size (major mode) can be confirmed either through examination of the REMOTS® photographs (rapid data return) or from grab samples and conventional laboratory grain-size analyses. Rejection of the null hypothesis would lead you back to Box 2.3; acceptance of the null hypothesis would lead to the next tier now that a change in physical attributes has been eliminated as a possible explanation for the anomalous colonization pattern.

Another physical factor is the mass or geotechnical properties of disposed sediments. Sediments which have very high water content (non-Newtonian muds) may not provide settling larvae with adequate support to keep them at or near the sediment-water interface until adequate consolidation has occurred. Conversely, disposed sediments representing over-consolidated "fossil" clays from deep excavation of channel bottoms may be too cohesive for penetration by infauna, or the concentration of detrital (labile) food may be too low in concentration in these relict clays to support growth. These same factors may affect (directly and negatively) larval choices for settlement.

Many of the above physical factors can be recognized from REMOTS® sediment-profile images. For example, changes in the physical attributes of the mound apex can be documented through sequential surveys. Difference in geotechnical properties between the mound and ambient bottom are detectable from the amount of prism penetration and the appearance of the sedimentary fabric. If evidence for adverse physical factors are present, it is accepted as the most parsimonious explanation for the anomalous nature of colonization documented. Monitoring then is continued back in Tier I, and the colonization status of the mound is rechecked after 6-12 months.

Underlying Assumptions: The management decision not to implement any further action and to continue to monitor colonization is based on the assumption that, over time, the physical properties of the sediments will come into some kind of "steady state" condition that will allow successful, albeit slower, colonization. For example, scour of the mound apex will be limited by the armoring effect, sediments will consolidate to accommodate recruitment, or "tight" sediments will be disaggregated gradually and mixed with ambient sediments to permit colonization.

Sources of Uncertainty: Note that the identification of an unsuccessful colonization may be attributed solely to an observed physical factor when, in fact, the cause is multifactorial. For example, quasi-fluid sediments may also contain high inventories of sedimentary sulfides and/or particle-bound metals, PAH's, or insecticides. The identification of a physical factor is sufficient to identify a cause for an anomalous colonization, but it may not identify all contributing factors.

4.2.3 Tier Three: Chemical Effects and Related Management Decisions

This tier is addressed if an anomalous rate of colonization is identified, yet no physical factor has been identified in Tier 2 as a potential and likely cause.

Box 2.7 "Sediment Bioassays and Other Measurements"

Because disposal mounds tend to be heterogeneous physical and chemical mixtures of sediments, it is likely that only part of a mound will show anomalous rates of colonization related to the discontinuous spatial distribution of inhibitory substances or conditions. Once locations of poor recruitment have been identified in a REMOTS® survey, sediment samples are taken at these stations using a grab or box core to collect sufficient volume for the required laboratory tests. These near-surface sediments are then used to conduct sediment bioassays using either the same protocols as required in the original permit (EPA/NED, 1989) or additional tests may be added to evaluate the sensitivity of the initial permit tests. Other analyses may be included at this point such as ammonia and sulphide leachate tests, or an evaluation of dissolved oxygen at the site. Numerous causes for the apparent toxic response are possible, and evaluation of the appropriate tests and measurements must be considered on a project-by-project basis.

Box 2.8 "Toxic Response?"

Results from the laboratory bioassay tests (animals placed in sediment from the disposal mound) are compared with animals in sediment from the reference stations; as before, the bioassay tests are for acute response. Chronic tests currently are under development by the USACE and EPA and could be used when they become available. The unstated null hypothesis is:

H_0: Mortalities of organisms in sediment from the disposal mound are not significantly different from reference.

Rejection of the null hypothesis will place you in Box 2.10 and requires following the tiered protocol outlined in Section 5 of this report; acceptance will place you in Box 2.9, indicating no cause for alarm and will lead to repeated periodic monitoring (Box 2.3). If high mortalities are observed in both the disposal site and reference sediments resulting in acceptance of the null hypothesis, one will need to re-evaluate either the assessment technique or explore the possibility that the reference sediments have been contaminated.

If the sediment originally passed the permit requirements, why might the disposed sediment fail a second round of bioassay tests? Samples taken for the initial permit may have missed contaminant "hot spots", or contaminants in the original test may have been in a form unavailable to the test organisms. As materials are excavated and disposed, redox conditions can change; this in turn may affect the partitioning coefficient of a pollutant compound between particles, interstitial water, and organic carbon. This phenomenon possibly can have an effect on the bioavailability of contaminants. One needs to examine in detail the difference in mortalities among the disposal, reference, and control sediments and use best professional judgment to explore the most parsimonious explanation for a toxic response at this point.

Underlying Assumptions: Results of the bioassay test are assumed to explain the failure of species (e.g. spionid polychaetes) other than the test organism(s) to colonize a disposal mound. Other assumptions about the adequacy of sediment bioassay testing were given in Section 3 and the discussion of Figure 1 (see Box 1.7).

Sources of Uncertainty: The assumption that the bioassay test is an adequate "surrogate" test for other organisms is untested. For example, amphipod crustaceans (used as a mid-range sensitivity species in the laboratory bioassay) are probably more sensitive to a wide range of sediment contaminants than spionid or capitellid polychaetes which are known to colonize highly contaminated sediments. This inference is based on the observation that spionids and capitellids are found in contaminated sediments that are not colonized by amphipods. If a tested sediment kills a large proportion of the tested amphipods (Box 2.8), these results may be sufficient to explain the failure of polychaetes to colonize a disposal mound but the species-to-species extrapolation is one based largely on faith. The best use of the amphipod test would be to explain the failure of amphipods (a Stage II taxon) to colonize a mound in the n+1 years (Box 2.4). Other sources of uncertainty related to bioassay testing are discussed in detail earlier (see discussion in Box 1.7).

Box 2.9 "Assume Due to Physical or Biological Processes; Reassess in 6-12 Months"

If no toxic response is observed in the bioassay test species, the logic path leads to an apparent paradox. The cause for a failure of recruitment is not identified from the measured or observed physical-chemical features of the deposit.

Underlying Assumption: The conclusion is that the cause for the observed colonization anomaly is related to a physical or biological factor that either has been overlooked or not been measured adequately in the monitoring program. For example, intrinsic properties of the recruitment process itself such as decreased reproductive success of parent stocks or external factors such as bottom

hypoxia or intense trawling activity may be responsible for the anomalous patterns observed.

Sources of Uncertainty: If the logic flow leads one into Box 2.9, this can be a frustrating result from both a scientific and management perspective. A careful review of the data and measurement program must be made at this point. One must also attempt to address the likelihood that factors extraneous to the measurement program may be influencing colonization. For example, the disposal site may have been affected by hypoxia while the reference stations (representing the ambient seafloor), because of their location, were not affected by hypoxia. If this appears to a plausible hypothesis, near-bottom oxygen measurements might be added subsequently to the monitoring program.

It cannot be over-emphasized that the monitoring protocol illustrated (Figure 2) does allow for flexibility; as additional management issues or objectives are identified, the monitoring protocol can be revised. If the measurement program fails to identify a specific cause for recruitment, the option always exists for a conservative management approach; this would involve going directly to box 2.11 (capping) instead of Box 2.9 (reassessment). This option might prove less costly if one is adamant about determining the cause for the anomalous recruitment, especially if clean capping material were readily available within the dredging project area. However, if an anomalous recruitment pattern is observed and one decides to cap without determining the specific cause for the departure from the expected, any shortcoming in the initial permitting evaluation which may have been responsible will continue to exist and potentially cause repeated problems in the future.

Box 2.10 ***"Re-Evaluate Assessment Procedure. Cap Disposal Mound"***

If a toxic response of the tested bioassay organisms is obtained, it is necessary to re-evaluate the initial permit testing procedure. Why did the material originally tested pass the permit evaluation screening while the sediment from the disposal site fails the test? These are the same issues discussed above for Box 2.8.

Underlying Assumptions: The assumption is that the permit testing was not adequate to identify toxic sediment or that the toxics are more available to the tested organisms due to diagenetic or "weathering" factors of the sediment at the disposal site.

Sources of Uncertainty: It may not be possible after-the-fact to identify the causes for the disparity between the permit test results (low levels from bulk chemistry screening or bioassay results showing no or equivocal toxicity) and the post-disposal results (toxicity shown in bioassay). To further address this problem would require a considerable research effort on the bioavailability of a wide range of contaminants under a wide range of Eh-pH conditions.

Box 2.11 ***"Go To H_o2: Capping Evaluation Flowchart"***

The decision of where and when to cap depends on the availability of appropriate capping material from scheduled projects. Once the capping operation has been completed, the monitoring protocol outlined in the next section will be followed (Figure 3).

The plan as outlined above is intended to be executed on an annual basis at all active containment disposal sites in the New England region. This tiered monitoring program for unconfined aquatic disposal can be applied where disposal projects are completed in the early spring; disposal operations stop during the summer months, and the mounds are available for primary and secondary succession without the complicating factor of continued disposal. At those sites where disposal occurs on a year-round basis (e.g., Massachusetts Bay), this monitoring plan can be instituted once the mound reaches a sufficient height and the disposal point is moved to another location within the site.

It is not uncommon in the New England region for disposal mounds to be built up over 2 or more years; large maintenance projects may require more than one dredging season to complete. Monitoring of these incomplete projects still is intended to occur on an annual basis (and as indicated earlier, would best take place during mid to late summer when biological activity is at its zenith). This interim "range" monitoring serves the purpose of assessing initial compliance. All of the conditions of successful colonization (Box 2.1 and 2.2) are expected to be met. If colonization is not successful, management may decide to await completion of the project before an extensive Tier Two and/or Tier Three investigation is carried out.

5.0 TIERED MONITORING SCHEME FOR CONFINED AQUATIC DISPOSAL

5.1 Background

If the decision is made at NED to allow open-water disposal of dredged material only if capping occurs, then a tiered monitoring strategy (Figure 3) more involved than the one presented in the above section is followed. If one refers back to the management overview (Figure 1), this decision point would be reached if one arrived at Box 1.12 via Box 1.10. A quick glance at Figure 3 reveals this decision has important ramifications as far as the commitment to long-term monitoring. Capping is not just an "out-of-sight, out-of-mind" alternative; it is an option which requires long-term model verification and trend monitoring to insure that isolation of disposed contaminants is achieved as originally planned.

The hierarchical flowchart presented for consideration was derived from the assumption that the mound being monitored is one specifically designated as a capping project, i.e., a major disposal operation that would result from sequential barge-loads of "contaminated" sediment followed by sufficient material to cover and isolate the sediment from the ambient environment. Many of the assumptions behind this hierarchical structure (discussed below) would not be valid for a mound built during routine disposal operations where "de-facto" capping occurs. De-facto capping is the term used by NED to describe the staged disposal of small amounts (e.g., 5,000-10,000 m^3) of questionable material at that season's routine disposal point within a particular site, along with and followed by sequential disposal of substantial amounts of what was classified during the permit evaluation process as "clean" material. Typically, what would happen is that disposal of contaminated material would occur early in the disposal season, so there might be a total of 20,000 m^3 (disposed in discrete increments of 2,000 - 5,000 m^3 at a time) of questionable material dispersed in various pockets in a mound with a total volume in excess of 200,000 m^3. If disposal of contaminated material is scheduled toward the end of a disposal season, at least 3 times the volume of clean material compared to the contaminated sediment volume would be scheduled as an absolute minimum to serve as the cap.[2]

Capping operations under the DAMOS program have been carried out at the New London, Portland, Brenton Reef, and Central Long Island Sound Disposal Sites (SAIC, unpub.). The tiered monitoring plan proposed would be applicable to mounds such as those at Cap Sites 1 and 2, STNH-N, STNH-S, and MQR, where substantial

2 One could argue effectively that the standard practice of "de-facto" capping at routine mounds would result in another unknown confounding variable if the monitoring strategy presented in Figure 2 shows adverse biological impacts (Box 2.8 in Tier 3); these negative effects could be due to insufficient capping and not because the initial assessment procedure is faulty.

volumes of contaminated material (between 20,000 - 70,000 m^3 or more) were placed at one disposal point and then covered with clean material. The intended result of capping operations is to produce a cross-sectional mound profile that would consist of two chemically distinct layers: a basement layer of contaminated material covered by a layer of clean material, as opposed to the random, mottled cross-sectional mix of contaminated and clean material one would find in a mound where "de-facto" capping had occurred. The overall, reigning null hypothesis for this tiered strategy is:

H_0: Capping has isolated all sediment contaminants effectively.

The monitoring tasks done to accept or reject this hypothesis, along with the underlying assumptions and sources of uncertainty, are discussed below. The main objective is to verify that indeed contaminants are not leaching upward through the cap material and are not becoming available to the ambient environment.

5.2 A Two-Tiered Monitoring Protocol For Capped Mounds

5.2.1 Tier One: Biological Processes and Related Management Decisions

Many of the monitoring procedures and logical flow of tasks are similar to those described in Section 4. However, there are some important differences which will be pointed out under the appropriate subheadings.

Box 3.1 ***"Verify physical coverage of mound; characterize chemicals in surface sediments"***

As mentioned previously, physical monitoring of all DAMOS disposal sites takes place on a routine (annual) basis; this background physical monitoring plays an important role in the verification of capping projects. Experience gained from the other capping projects done at the Central Long Island Sound Disposal Site (SAIC, unpub.) has shown that strict operational control of disposal events is needed to insure creation of a successful cap. Contaminated sediment disposal must be performed at a taut-wire mooring marking the target location, and a combination of precision bathymetry and REMOTS® surveys must be performed at the completion of contaminated sediment disposal to confirm the areal extent of contaminated sediment on the bottom. REMOTS® profiling is used to map the thickness of dredged material from 0-20 cm thick; acoustic profiling is used to map the presences of disposed material ≥ 20 cm thick.

Once this has been documented, a capping plan can be developed for subsequent disposal operations to maximize the areal coverage of the contaminated sediment by clean material. Immediately following completion of the capping operations, another combination of precision bathymetry and REMOTS® surveys will be performed to insure complete coverage of the contaminated material with the minimum thickness required in the disposal project permit. Past experience has shown that typically a

minimum thickness of 50 cm to one meter is required for the cap; chemical isolation by the physical covering of sediment can be achieved usually with a layer of approximately 35 cm (Gunnison, *et al.*, 1987). The additional 15 to 65 cm is recommended as insurance against excessive perforation of the capped layer by burrowing infauna. The majority of bioturbating fauna in Long Island Sound are found in the upper 15-20 cm of sediment (Germano, 1983); however, stomatopods (e.g., <u>Squilla</u>), decapods (e.g., <u>Homarus</u>), and some fish (e.g., <u>Urophysis</u>) can burrow much deeper than this, sometimes in excess of a meter. However, the densities of these burrowing megafauna are low enough to dismiss the occasional perforation of the cap by their burrow as not serious enough to compromise the integrity of the overall cap function.

Sediment samples are to be taken with a grab both on the disposal mound and at the reference stations for baseline chemical characterization; unless the permit evaluation testing has identified a unique organic compound as a signature for the underlying contaminated material, the sediments will be tested for physical characteristics (grain-size) and the same suite of contaminants as done for the initial permit evaluation. Obviously, if a unique chemical signature has been identified for the contaminated material, levels of that compound will also be analyzed (with the expected results being a no detection level). In the absence of any unique chemical signature, these "time-zero" levels are not to test any null hypothesis, but to serve as a baseline level against which future sediment tests shall be compared (e.g., Box 3.14).

<u>Underlying Assumptions</u>: Once monitoring is initiated following this protocol, it is assumed that complete physical coverage of the contaminated sediment has occurred and been verified by the bathymetry and REMOTS® surveys. The other, and equally important assumption, is that the cap material has low contaminant levels and is verified as not having a toxic bioassay response, to eliminate phenomena such as the recolonization anomaly witnessed at the MQR disposal mound at the Central Long Island Sound Disposal Site.

<u>Sources of Uncertainty</u>: If the cap material has low bulk chemistry contaminant levels, there would be no need to go through the expense of bioassay/bioaccumulation testing as part of the initial permit evaluation. There still remains a very small possibility that some "mystery compound" not analyzed could be responsible for causing an anomalous recolonization pattern. However, unless the majority of monitoring results from routine unconfined open-water disposal monitoring (Figure 2) shows that there are serious problems with the evaluation protocol, there is no reason to justify the additional expense of bioassay testing for capped material when the normal evaluation procedure shows it is not warranted. If one were to "err on the conservative side" as an added level of safety for capped projects, one could argue by the same logic that the same conservative steps should be taken for

all disposal projects, regardless of the bulk chemistry results.

Box 3.2 "Mound Covered?"

Immediately following completion of a capping operation, physical monitoring is conducted to assess compliance, i.e., has the mound been capped completely with a specified thickness of capping material? This evaluation typically involves a precision bathymetric survey possibly combined with a sub-bottom profiling survey (project conditions usually require a cap thickness of at least 50 cm, which is well within the resolution of acoustic measuring techniques). If necessary, the REMOTS® camera can be used to map cap thickness on the mound flanks when the capping material has textural or optical properties (grain-size or reflectance) that are unique from the underlying disposed material. If the cap meets both the thickness and coverage criteria, post-disposal trend monitoring begins in Box 3.4.

Box 3.3 "Add More Capping Material"

If the capping operation has failed to cover all of the disposed material with the designated minimum thickness, further capping operations are necessary. This may involve the use of the same capping material as initially used, or the NED may identify another "project-of-opportunity" to complete the capping project. Once the recapping has been completed, the mound is revisited to assess compliance (Box 3.1). If recapping is successful, trend monitoring begins (Box 3.4)

Box 3.4 "Assess Population Density of Stage 1 Organisms ..."

This task would be carried out exclusively with REMOTS® technology as before because of the quick data return and relative cost savings over traditional monitoring techniques. See the explanation in Box 2.1 in the previous section for further details.

Box 3.5 "Stage 1 Population Density Greater Than References?"

Once again, the predicted response of ecosystem recovery following the cessation of capping operations would be the colonization of the area by dense assemblages of Stage I pioneering polychaetes. The unstated null hypothesis being tested is:

H_0: The population density of opportunistic polychaetes on the disposal mound as detected in REMOTS® photographs is not less than that on the ambient seafloor outside the disposal site boundaries.

Acceptance of the null hypothesis would lead one to Box 3.10; rejection of the null hypothesis would lead to Box 3.6. Other considerations for this particular step are similar to those discussed in the previous section for Box 2.2.

Underlying Assumptions: If capping has been carried out by placing medium or coarse sand over a silt/clay contaminated mound in an area that is predominantly a muddy seafloor, one would expect to see a different recolonization pattern

initially. If a cap of a different grain-size is a known initial condition, rejection of the null hypothesis would lead to Box 3.6, but no further action would be warranted, because the answer to the question posed in Box 3.7 is a given.

Box 3.6 ***"Evaluate Physical Effects"***

Samples for sediment grain-size would be taken only if an anomalous grain-size major mode is not obvious from the REMOTS® photographs (and would need ground truth confirmation) or it was not already a given that capping operations had been carried out with fine or medium sand. The chances for the need of having to take samples at this point if one arrives at this box via Box 3.5 are exceedingly slim; the cap sediment grain-size would be known from both the REMOTS® surveys done up to this point and the initial sediment characterization done in Box 3.1.

Box 3.7 ***"Have The Physical Properties of the Mound Changed?"***

If one arrives at this box via Box 3.5, the initial recruitment pattern may be different if a sand cap is used to cover the contaminated material. If one arrives via Box 3.11, the effects of erosion and scour could be affecting the normal recolonization pattern; these are discussed in more detail in the previous section in the text following Box 2.6. The unstated null hypothesis being tested is:

H_0: The sediment grain-size major mode on the disposal mound is not different from the ambient seafloor.

Acceptance of the null hypothesis would lead to Box 3.8 to explore possible sediment toxicity due to chemical impacts; rejection of the null hypothesis would lead to Box 3.10. See the discussion under Box 2.6 in the previous section for underlying assumptions and sources of uncertainty.

Box 3.8 ***"Collect Sediment For Laboratory Bioassay Studies On Selected Infaunal Species"***

If there is no apparent physical effect responsible for the anomalous recolonization pattern detected, then sediment samples must be collected from both the disposal mound <u>and</u> the reference stations to examine the possibility of sediment toxicity. Sediment samples are needed from the reference areas both to serve as a control for the laboratory bioassay and to eliminate the possibility of general regional deposition of material which may be affecting recolonization adversely (e.g., unusual storm runoff or heavy CSO output which could dump a high contaminant load in an area such as western Long Island Sound). If the latter possibility were true, one would expect to see a toxic response in the laboratory both to the experimental (mound) sediments and the controls (reference stations). Once again, both the original protocols used in the permit testing (EPA/NED, 1989) or additional tests may be added to evaluate the possible causes for anomalous recolonization; see the previous discussion under Box 2.7 for

more details.

Box 3.9 "Toxic Response?"

As emphasized in the previous sections, these bioassay tests are for acute responses (mortality) only and will continue to be used until chronic tests are available. The unstated null hypothesis is:

H_0: Mortalities of organisms in sediment from the disposal mound are not different from references.

Rejection of the null hypothesis will place you in Box 3.17 in Tier 2; acceptance will place you in Box 3.10 indicating no cause for alarm and will lead to repeated periodic monitoring. See the discussion in the previous section under Box 2.8 for additional explanation.

Box 3.10 "Acceptable Response; No Immediate Action. Periodic Monitoring"

One can arrive at this box from 6 different routes (via boxes 3.5, 3.7, 3.9, 3.13, 3.20, or 3.21); all routes assume the outcome of a predicted or possibly unexpected but acceptable response. Arrival in this box indicates there is no cause to believe at this point that the integrity of the cap has been compromised. For the most part, "periodic monitoring" means continue to monitor on an annual basis during the mid to late summer. If conditions warrant high-resolution monitoring, an additional REMOTS® survey could be performed within 2-3 months following the survey which initially led to this box.

Underlying Assumptions: Monitoring on an annual basis (as has always been done under the DAMOS program) assumes that seasonal variability is not critical and will not reveal any unknown impacts of dredged material disposal.

Box 3.11 "Stage 2 or 3 Community Develop After N+1 Year(s)?"

See the discussion in the previous section under Box 2.4 for details and assumptions associated with this step of the monitoring protocol. The unstated null hypothesis being tested is:

H_0: Stage 2 or 3 assemblages (deposit-feeding taxa) are present on the disposal mound following one year from cessation of disposal operations.

Once again, data are collected with REMOTS® technology; acceptance of the null hypothesis would lead to Box 3.12. Rejection of the null hypothesis would lead back to Box 3.6 to evaluate the potential for physical effects as the cause of the unexpected recolonization response.

Sources of Uncertainty: If the mound has been capped with predominantly sand, it is quite possible that the successional paradigm predicting an appearance of infaunal deposit feeders will not be a valid model. While the appearance of a Stage II community could occur (a dense assemblage of amphipods at the sediment surface) on a sand

substratum, the progression to a Stage III community of deep-dwelling, infaunal deposit-feeders may never occur. If this is the case and one blindly followed the flow chart, one would be trapped in an endless loop among boxes 3.6, 3.7, 3.10, and 3.11. Clearly if the sand substratum persists after the first year and results in an anomalous recolonization pattern, one would still progress to Box 3.12.

If a sand cap is placed over a contaminated mound in an area that is predominantly a silt/clay bottom, it is more likely that natural deposition of detritus as well as the phenomena of transport and deposition will slowly change the surface layer of the cap from a sand to a progressively muddier substratum as time passes (as observed in cores collected from the STNH-N and Cap Site 2 mounds at the Central Long Disposal Site). When this occurs, the expected successional sequence of change to a mature, deposit-feeding community over time still will be a valid prediction.

Box 3.12 ***"Collect Surface Sediments and Infaunal Species for Chemical Analyses"***

This is the first notable departure from similarity with the monitoring protocol outlined in the previous section for unconfined open-water disposal and constitutes the "next level of assurance" for monitoring capped disposal mounds. Even though recolonization is proceeding normally (indicating the lack of any apparent toxic compounds in the sediment), this step represents the next attempt to verify that no contaminants are leaching through the cap.

Separate sediment samples as well as representatives of identical species of indigenous fauna are collected from the disposal mound and the reference areas. Instead of assuming a particular target species, the investigators will determine the faunal dominant by collecting sediment and sieving to find out what are the dominant taxa. Typically, either the polychaete Nephtys incisa, any dominant large bivalve, or one of the common gammarid amphipods are collected in sufficient quantity for tissue contaminant analyses.

Box 3.13 ***"Are Body Burden Levels Higher Than Those From Reference Areas?"***

Box 3.14 ***"Are Contaminant Levels Higher Than Time Zero Levels?"***

Both Box 3.13 and 3.14 are dealt with simultaneously at this point; the numerical ordering of the boxes does not indicate sequential collection or analyses. Sufficient biomass of the target species are frozen immediately after collection and shipped to the laboratory for analyses. The unstated null hypotheses being tested regarding tissue concentrations is:

$H_0$1: Infaunal tissue contaminant levels are not higher on the disposal mound than those on the ambient seafloor.

Surface sediments associated with these organisms are obtained with a grab for analysis. The same

contaminants are analyzed as those in Box 3.1 and comparison is made with the time zero levels. Sediment samples collected from the disposal mound and in the reference area are compared with the following null hypothesis in mind:

H_o2: Contaminant concentrations in surface sediments are not higher than at time zero levels.

If the H_o1 null hypothesis is accepted, the logic returns us to Box 3.10. If the H_o1 null hypothesis is rejected, H_o2 becomes important as a potential explanation for the observed increase in tissue contamination. If contaminant concentrations in surface sediments are higher than time zero levels (H_o2), the source of this contamination is explored in Box 3.16. If the surface sediment is not higher than at time zero, an alternative explanation is required (Box 3.15). Because of the high costs associated with field collection of biomass (it can sometimes take a full day to collect sufficient biomass of infauna at a single station) and subsequent laboratory analysis, usually sufficient biomass for three replicate samples is collected from only one general location on the disposal mound and compared with three replicates from the ambient seafloor. Regarding sediment sampling, a sufficient number of replicates must be collected to detect at least a 50% difference in time zero levels; this number of replicates can be determined by calculating power levels for the statistical model used (Cohen, 1977; Bernstein and Zalinski, 1983). Once again, unless there was a unique chemical signature in the underlying contaminant material, the same suite of contaminants analyzed during permit evaluation (8 metals, PCB's, total PAH's) would be the same ones being tested at this point. See the discussion accompanying Box 1.7 in Section 2 for further considerations at this point.

Underlying Assumptions: One assumes that if contaminant levels are detectable and different from time zero levels, then they will be greater. These is a possibility for contaminant levels to be less than those measured at time zero because of the phenomenon described earlier (fine sediment being winnowed from the apex of the disposal mound). Because most contaminants are associated with fine-grained sediments, as the mound loses fines, surface contaminant levels could decrease. One can guard against this by not collecting sediment from winnowed areas; these areas would be identified by the earlier REMOTS® monitoring.

Another assumption in this step of the monitoring protocol is that the one organism collected for laboratory analysis is a good representative of the majority of infauna present at the disposal mound. It also is assumed that non-polar organic compounds are the main contaminants of concern; polar organics are not tested at any step of the way.

Sources of Uncertainty: Sometimes, time zero levels of sediment contaminants are lower than ambient levels (hence the need for collecting sediment at the reference

stations both at time zero and now) and will increase over time due to natural deposition of fine grained material. If levels are higher, there is still a distinct possibility that it is due to an errant disposal event and not migration of chemicals through the cap (hence the need for the next tier for verification). If both the disposal mound and the ambient seafloor show similar levels of increase, the most parsimonious explanation is that it is due to regional deposition of contaminated detritus.

As far as sources of uncertainty for interpreting the results from the infaunal body burden analyses, in addition to the appropriate ones listed under Box 1.7 in Section 2, there are a number of potential unknowns that could affect the interpretation of the final results:

- The final data are species-specific; the relevance to other species can always be questioned, and the inability to collect the same species at the same locations in subsequent years may hinder long-term trend monitoring.

- It is difficult to account for seasonal variation in lipid content (which has a direct effect on body burden levels of contaminants); unless all individuals are in the same stage of ontogeny and reproductive maturity at all locations and at each subsequent sampling time, any variation is not necessarily due to contaminants leaching through the cap.

- There are no regulatory criteria established for the majority of invertebrate species or for contaminants (the FDA has set action limits in seafood for PCBs, a few pesticide compounds, and methyl mercury, but not for PAHs and any other metals of concern), so trigger levels are arbitrary. Attempts to find "meaningful" levels of change are often confused with statistically "significant" levels of change. Given enough of an intensive sampling effort, a very small change can be statistically significant. Because of our lack of knowledge about "normal" invertebrate biochemical levels and metabolic pathways, <u>any</u> trigger level at which we choose to reject the null hypothesis is arbitrary. This is without a doubt the most serious flaw in this whole procedure; because of the large variability which typically exists in tissue contaminant levels, we define an order of magnitude difference between the disposal mound and reference as being "significant" enough to reject the null hypothesis.

- If the null hypothesis (H_01) is accepted, there is still the possibility that some unknown chemical (not being analyzed in the tissue) that will exert a chronic, deleterious impact on invertebrate species is still bioaccumulating but simply not

being measured. One could argue this is highly unlikely, because if unknown or "mystery" chemicals can leach through the cap, chances are the same route of transport would be available to those chemicals which are being measured in the tissues and would show up as abnormally high levels.

- Because of the expense associated with bioaccumulation studies, the number of samples analyzed is typically small (3 replicates from the mound are compared with 3 replicates from the ambient seafloor). Different levels of variability are associated with different contaminants; the most notoriously variable are the organics. Some compounds (e.g., PCB's) have demonstrated such a high coefficient of variation in samples collected to date that as many as 20 replicates would need to be collected to detect a 50% difference at an alpha level of 0.05 (DAMOS database, unpublished). If contaminants that will trigger management actions have inordinately high variability, then explicit computation of power relative to a small sample size (e.g., Cohen, 1977) should be carried out before further sampling is performed. Such computations often lead to the realization that there is no point in doing the study unless the sample size is doubled or quadrupled. If the resources do not exist, there is no point in collecting only a fraction of the data needed to make a defensible statement; studies deficient in statistical power result in a large proportion of invalid rejections of the null hypothesis (Overall, 1969).

Box 3.15 ***"Seek Alternate Explanation"***

One can reach this box via Box 3.14 or 3.21. In either case, one has arrived at this point because bioaccumulation may have occurred (via Box 3.13) and surface sediment contaminant levels may (via Box 3.21) or may not (via Box 3.14) be higher than time zero levels. If the increase in invertebrate tissue contaminant levels is due to either an errant disposal event or regional deposition, then there is no need to supply additional capping material to the mound or re-evaluate the current capping management protocol. This will force you back to Tier 1 in Box 3.10.

5.2.2 Tier Two: Mound Chemical Profiling and Related Management Decisions

Boxes 3.16 & 17 ***"Determine Source of Contamination....."***

Once you have arrived in Tier 2, all indications are pointing toward the cap being breached. Results of the physical monitoring program become important at this point to help identify locations and sources of cap breaching. Piston, gravity, or vibra-core sampling will need to be done at several locations (3-5) through the mound into the underlying contaminated sediment. Samples should be taken at

the central portion of the mound as well as along the flanks.

Box 3.18 *"Evidence of Contaminants Migrating Through Cap?"*

If a sand cap is in place, it will be easy to distinguish the boundary between the cap and the contaminated material visually. The two layers should be separated and sectioned vertically, properly labeled, and sent to the laboratory for analysis. If there is not a distinct grain-size discontinuity (e.g., when a silt/clay cap is used on contaminated muds), vertical sections ($\tilde{}$10 cm) should be made starting at the top of the core and working down to the bottom.

One has arrived at Box 3.18 because the initial post-disposal monitoring has shown anomalous recolonization, no detectable physical explanation, and a toxic sediment response to laboratory bioassays or because the same sequence of events occurred after more mature successional stages were not found on the mound following one or more years. The only two possibilities are that the cap had been breached (contradicting the results of Box 3.1 if it occurs as a result of the immediate post-disposal monitoring), or an errant disposal event has deposited contaminated material on top of the surface capped layer. The underlying assumption is that the cap material is chemically distinct from the underlying contaminated material; the unstated null hypothesis being tested is:

H_0: There is no gradient in contaminant levels between the contaminated and capped layer.

Acceptance of the null hypothesis would force you to conclude an errant disposal event had occurred and lead you to Box 3.19; rejection of the null hypothesis would lead to Box 3.22 and require further capping material be placed on the mound.

Because it is unknown what compound(s) is(are) responsible for the toxic bioassay response, one would be forced to analyze each separate vertical section of sediment for the maximum number of contaminants possible within budgetary constraints, presumably the same standard suite that has been tested repeatedly to this point (again, assuming there are no unique organic and inorganic compounds that can be used as a tracer for the underlying contaminated sediment; if these tracers are present, then these compounds are the only ones for which the vertical sections need to be analyzed).

<u>Sources of Uncertainty</u>: Because the only time zero chemical levels collected at this point are just surface contaminant levels, the surface interval is the <u>only</u> comparison one will be able to make with time zero levels. All the other data from the subsurface intervals in the piston or gravity core can be considered only baseline data at this point against which future evaluations can be compared. It is also quite likely that if there is evidence of contaminant migration, it will not be a uniform pattern that all compounds will follow; more than likely, the data will display the same variability as surface

sediment bulk chemical analyses and lead to the same types of problems with interpretation as discussed under Box 1.4 in Section 2.

Box 3.19 "Evaluate Areal Extent of Toxic Material"

If there is no evidence of contaminant migration, then an errant disposal event is the only logical explanation for the observed pattern occurring to this point. A REMOTS® survey should be repeated over the established mound sampling grid to see if any surface layer of new material (distinguishable by a visual or textural discontinuity in the upper sediment layer) has been deposited on the mound.

Box 3.20 "Does Errant Material Cover Substantial Portion of Mound?"

If errant material is not detectable in any of the REMOTS® photographs, then one must assume the errant disposal event(s) happened sufficiently long ago or resulted in a relatively thin layer so that it could be re-worked through bioturbation and visually indistinguishable from the original cap sediment surface. The other possibility is that the sediment used for the cap had high contaminant levels (i.e., was unsuitable as capping material). If errant material is visible on the surface of the mound but only at one or a few stations, one must decide whether the additional expense of capping the entire mound is justified (Box 3.22), or if one should wait and watch for the effects to disappear through dilution with the background sediments through natural depositional processes and subsequent bioturbation (Box 3.10). However, because one has reached this box because of a toxic response from laboratory bioassays (Box 3.9), the most conservative management action available is to proceed to Box 3.22 and cover those areas of the cap with more suitable capping material as soon as possible.

If only a small amount of errant material is detected and has been determined as the source of the problem, it would be the final decision of the DAMOS program manager at NED on whether or not additional capping operations should be carried out at this particular location. If the decision is made to wait, one would return to Tier 1 and Box 3.10 to reassess the situation in 6-12 months (Box 3.20 can be reached with no bioaccumulation testing if this pathway is taken during the first year of monitoring via Box 3.5).

Box 3.21 "Evidence of Contaminants Migrating Through Cap?"

See the discussion above for Box 3.18. The one major difference between this box and Box 3.18 is that one has arrived here because tissue contaminant levels and/or surface sediment levels are higher than time zero. Instead of analyzing for the entire standard suite of contaminants in each vertical section, one need only analyze for the contaminant(s) shown to be elevated in the tissues or surface sediments.

If a gradient can be demonstrated

so that there is evidence of contaminants migrating through the cap, this leads to Box 3.22 and an immediate replacement of the cap with more suitable material. If there is no evidence of contaminants migrating through the cap, the only reasonable concusion is that the negative impacts seen to this point are from regional phenomena or an errant disposal event, and not due to failure of the cap to isolate underlying contaminants. This would lead to Box 3.15 and back up to Tier 1, where the situation would be reassessed the following year.

Sources of Uncertainty: The main source of uncertainty is that one has arrived at Box 3.21 by never having done a laboratory sediment bioassay test. By relying on just bioaccumulation or bulk chemical analyses alone, we assume we can identify the contaminant of concern; given the limitations discussed under Boxes 1.4 and 1.7 in Section 2, we are relying on infaunal recolonization patterns to be the field analog of a laboratory bioassay.

As stated earlier, the decision to cap necessarily commits one to a long-term monitoring program. If one never progresses beyond Tier 1, then monitoring should occur on an annual basis for at least 4 or 5 years, on a bi-annual basis until 10 years post-capping, and then every 5 years on an indefinite basis.

6.0 CONCLUSIONS

The tiered protocols described here are the product of more than a decade of combined disposal site management and monitoring under the DAMOS Program. This is the first serious attempt to structure the monitoring program on a foundation of null hypothesis testing using sampling techniques with rapid data return. Given all the sources of uncertainty pointed out above, there is no doubt that the protocol will continue to evolve and be modified as time passes and we learn that some of our initial assumptions are incorrect. The important point is to not be lulled into complacency and let the monitoring program described in this document become a goal in itself; this has been designed to be a dynamic tool for decision-making by environmental resource managers, not a static, routine operation to generate endless volumes of grey literature that sit unused on shelves. This is a working document that will require periodic revision; it can only be improved by changing our ideas and approaches to monitoring as we gain a better understanding of environmental response to dredged material disposal.

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FIGURE 1. MANAGEMENT OVERVIEW

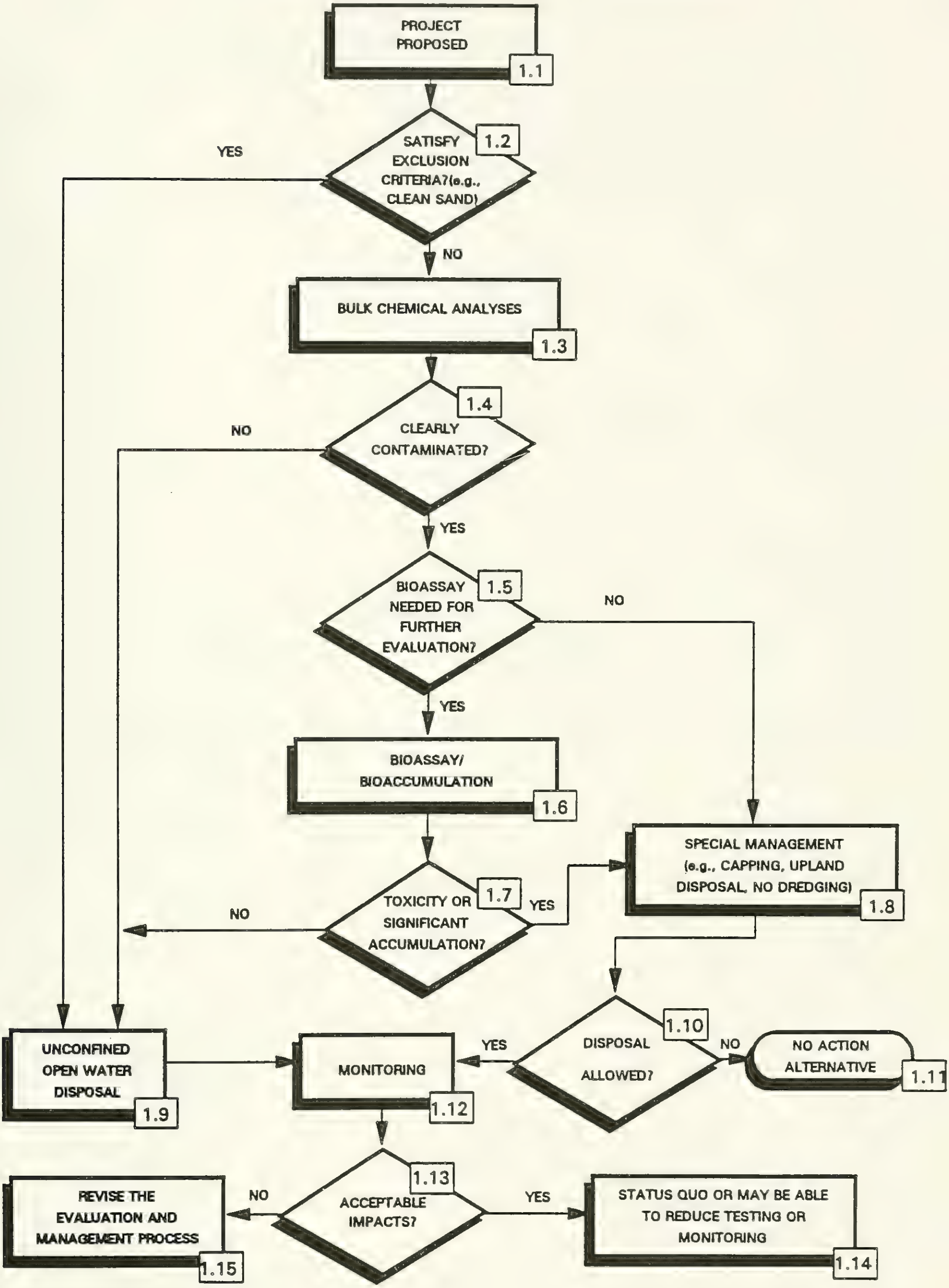


FIGURE 2. H_o1: ON AN UNCONFINED DISPOSAL MOUND, DREDGED MATERIAL DISPOSAL WILL RESULT IN BENTHIC POPULATION DENSITY GREATER THAN AMBIENT CONDITION

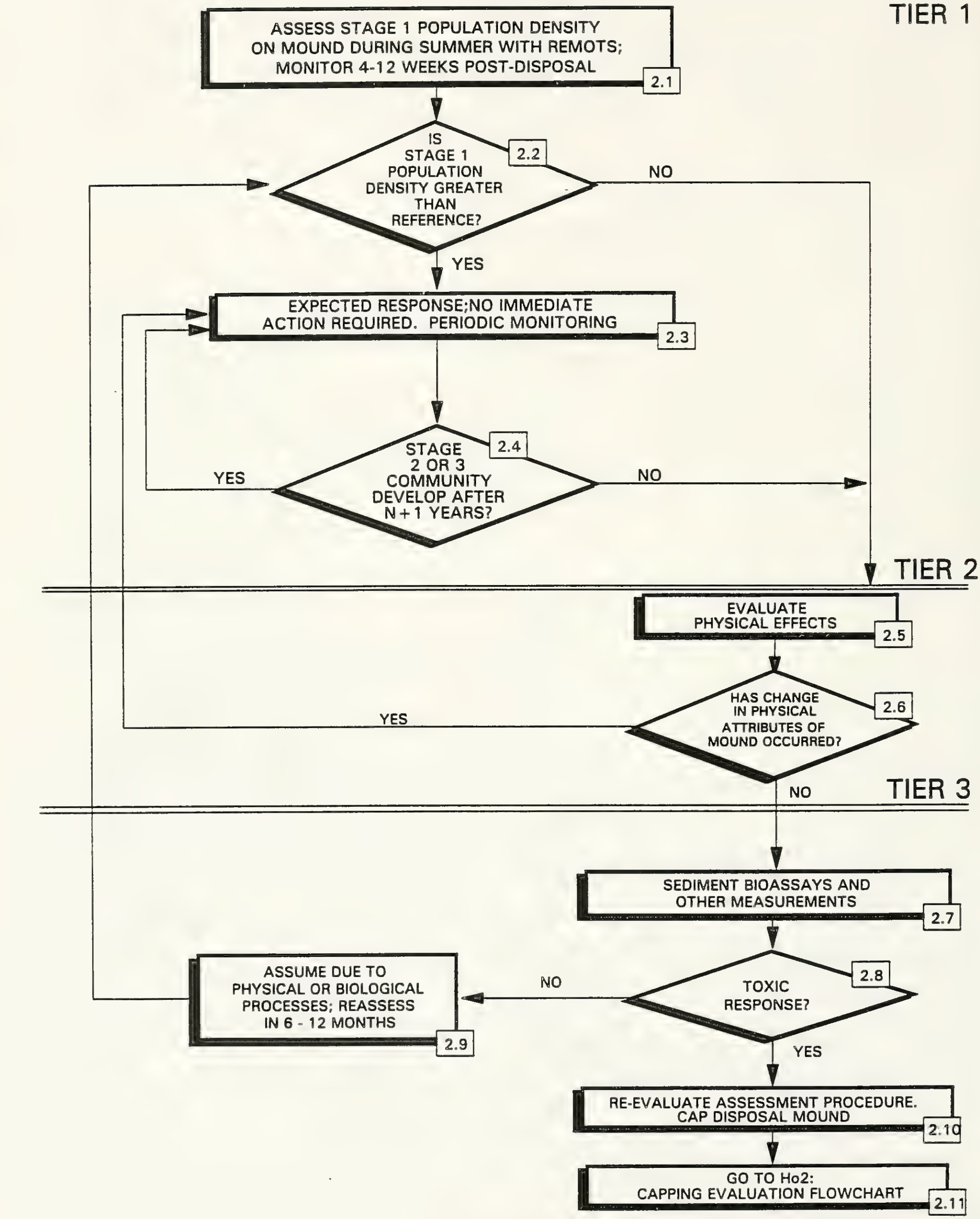
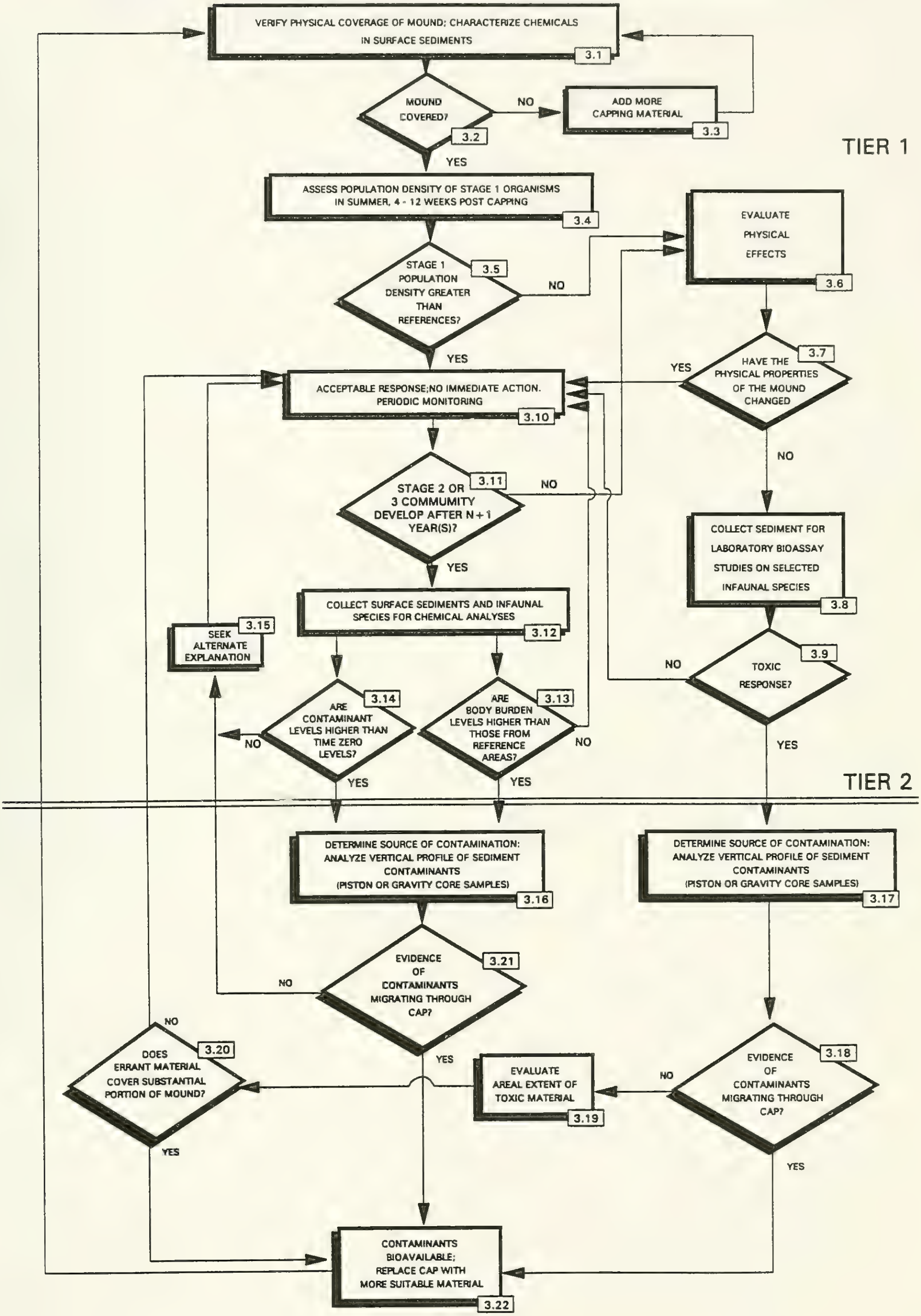


FIGURE 3. H_o2: CAPPING HAS ISOLATED SEDIMENT CONTAMINANTS EFFECTIVELY



Appendix A

Organisms Acceptable As Biological Testing Species (from Table II, page 17, EPA/NED, 1989).

Representative Test Species Used For Bioassay/Bioaccumulation Testing[1]

SUSPENDED PARTICULATE	WHOLE SEDIMENT[2]	BIOACCUMULATION[3]
Mysidopsis bahia	*Ampelisca abdita*	*Nereis virens*
Menidia menidia	*Nereis virens*	*Palaemonetes pugio*[4]
	Palaemonetes pugio[4]	*Macoma balthica*
	Macoma balthica	*Yoldia limatula*
	Yoldia limatula	*Mercenaria mercenaria*[5]
	Mercenaria mercenaria[5]	

1 All species chosen must be approved by the Corps of Engineers prior to testing.

2 Whole sediment bioassays must include three (3) species: a crustacean (preferably Ampelisca), the polychaete Nereis, and a bivalve (preferably Macoma or Yoldia).

3 Bioaccumulation testing must use survivors of the bioassay (except Ampelisca), including the polychaete Nereis, a bivalve (preferably Macoma or Yoldia), and Palaemonetes if it is used in the whole sediment bioassay.

4 This species may be used only if Ampelisca is unavailable.

5 This species may be used only if Macoma or Yoldia are unavailable.

Appendix B

Chemical Constituents[a], EPA Analytical Methods, and Detection Limits Used For Chemical Examination of Tissue (from Table III, pages 20-23, EPA/NED 1989)

Chemical Constituent (ppm)	Analytical Method	Detection Limit
% Lipids		0.1[b]
% Water		0.1[b]
METALS[c]		
Antimony	7040, 7041	0.01
Arsenic	7060, 7061	0.01
Beryllium	7090, 7091	0.1
Cadmium	7130, 7131	0.1
Chromium	7190, 7191	0.2
Copper	7210	0.1
Lead	7420, 7421	0.5
Mercury	7471	0.01
Nickel	7520	0.2
Selenium	7740, 7741	0.01
Silver	7760	0.02
Thallium	7840	1.0
Zinc	7950	0.1
ORGANICS		
PCBs	8080	0.2
Pesticides	8080[c]	0.002-0.03[c]
Aldrin		
Chlordane		
p,p-DDT, DDE, DDD		
Dieldrin		
Endosulfan I, II		
Endosulfan sulfate		
Endrin		
Endrin aldehyde		
Heptachlor		
Heptachlor epoxide		
α, β, δ, and γ-Hexachlorocyclohexane		
Methoxychlor		
Toxaphene		
MISCELLANEOUS		
Cyanide	9010, 9012	2.0
Phenolics	9065, 9066	1.0
Isophorone	8090	0.02
2,3,7,8-TCDD (Dioxin)	8280	0.002
2,3,7,8-TCDF (Dibenzofuran)	8280	0.002

TABLE III (cont.)

Chemical Constituent (ppm)	Analytical Method	Detection Limit
BASE/NEUTRALS[d]		
Aromatic Hydrocarbons	8100,8250, 8270[e]	0.01-0.02[b]
Acenaphthene		
Acenapthylene		
Anthracene		
Biphenyl		
Benzo(a)anthracene		
Benzo(b)fluoranthene		
Benzo(k)fluoranthene		
Benzo(a)pyrene		
Benzo(ghi)perylene		
Benzo(e)pyrene		
Chrysene		
Dibenzo(a,h)anthracene		
2-6-Dimethylnapthalene		
Fluoranthene		
Fluorene		
Indeno (1,2,3-cd)pyrene		
1-Methylphenanthrene		
1-Methylnaphthalene		
2-Methylnaphthalene		
Naphthalene		
Perylene		
Phenanthrene		
Pyrene		
Chlorinated Hydrocarbons		0.01[f]
1,2-Dichlorobenzene	8010,8020,8250,8270	
1,3-Dichlorobenzene	8010,8020,8250,8270	
1,4-Dichlorobenzene	8010,8020,8250,8270	
1,2-Trichlorobenzene	8010,8120,8250,8270	
2-Chloronaphthalene	8120,8250,8270	
Hexachlorobenzene	8120,8250,8270	
Hexachloroethane	8120,8250,8270	0.04
Hexachlorobutadiene	8120,8250,8270	0.04
Hexachlorocyclopentadiene	8120,8250,8270	
Phthalates	8060[e]	0.01[e]
benzylbutylphthalate		
bis(2-ethylhexyl)phthalate		
diethylphthalate		
dimethylphthalate		
di-n-butylphthalate		
di-n-octylphthalate		

TABLE III (cont.)

Chemical Constituent (ppm)	Analytical Method	Detection Limit
Halogenated Ethers	8110[e]	0.02[e]
bis(2-chlorethyl)ether		
bis(2-chloroisopropyl)ether		
bis(2-chlorethoxy)methane		
4-Bromophenylphenylether		
4-Chlorophenylphenylether		
Organonitrogen Compound		
Benzidine	8250,8270	0.02[e]
3,3'-Dichlorobenzidine	8250,8270	
2,4-Dinitrotoluene	8090,8250,8270	
2,6-Dinitrotoluene	8090,8250,8270	
1,2-Diphenylhydrazine	8090,8250,8270	
Nitrobenzene	8090,8250,8270	
N-Nitrosodimethylamine	8070,8250,8270	
N-Nitrosodiphenylamine	8070,8250,8270	
N-Nitrosodipropylamine		8070,8250,8270
ACID EXTRACTABLES[d]	8040[e]	0.02[f]
4-Chloro-3-methylphenol		
2-Chlorophenol		
2,4-Dichlorophenol		
4,6-Dimethylphenol		
4,6-Dinitro-2-methylphenol		
2,4-Dinitrophenol		0.1
2-Nitrophenol		
4-Nitrophenol		0.1
Pentachlorophenol		0.08
2,4,6-Trichlorophenol		
VOLATILES[c]	8010,8240,8260[f]	0.01[f]
Acrolein	8030,8240,8260	0.1
Acrylonitrile	8030,8240,8260	0.1
Benzene	8020,8240,8260	
Bromoform		
Carbon tetrachloride		
Chlorobenzene		
Chlorodibromomethane		
Chloroethane		
2-Chloroethylvinyl ether		0.1
Chloroform		
Dichlorobromomethane		
1,1-Dichloroethane		
1,2-Dichloroethane	8010,8240,8260	
1,1-Dichloroethylene		
1,2-Dichloropropane		

TABLE III (cont.)

Chemical Constituent (ppm)	Analytical Method	Detection Limit
VOLATILES[c] (cont).	8010,8240,8260[f]	0.01[f]
1,3-Dichloropropylene		
Ethylbenzene		
Methyl bromide		
Methyl chloride		
Methylene chloride		0.1
1,1,2,2-Tetrachloroethane		
Tetrachloroethylene		
Toluene	8020,8240,8260	
1,2-trans-Dichloroethylene		
1,1,1-Trichloroethane		
1,1,2-Trichloroethane		
Trichloroethylene		
Vinyl chloride		

[a] Chemical consituents required for testing would be stipulated by the Corps of Engineers in cooperation with other Federal resource agencies

[b] Units in %

[c] Follow extraction/cleanup procedures described in Tetra Tech (1986)

[d] Follow extraction/cleanup procedures described in Battelle (1985)

[e] Includes all compounds listed

[f] Includes all compounds listed except otherwise noted.